Final Report

Economic Assessment of Green Infrastructure Strategies for Climate Change Adaptation: Pilot Studies in The Great Lakes Region

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Eastern Research Group, Inc.

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ABBREVIATIONS, ACRONYMS, AND SYMBOLS

AREIS	Auditor's Real Estate Information System
ASFPM	Association of State Floodplain Managers
cfs	Cubic feet per second
CREAT	Climate Resilience Evaluation and Awareness Tool
CSC	Coastal Services Center
CSO	Combined sewer overflows
DEM	Digital elevation model
EAD	Expected annual damages
EPA	U.S. Environmental Protection Agency
ESRI	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
ft/s	Foot per second
GCM	General circulation model
GI	Green infrastructure
HEC-HMS	Hydrologic Engineering Center Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center River Analysis System
H&H	Hydrology and hydraulics
IPCC	Intergovernmental Panel on Climate Change
LID	Low impact development
MRLC	Multi-Resolution Characteristics Consortium
NED	National Elevation Dataset
NHD	National Hydrography Dataset
NOAA	National Oceanic and Atmospheric Administration
OMB	Office of Management and Budget
O&M	Operations and maintenance
PV	Present Value
SRES	IPCC *Special Report on Emissions Scenarios*
TP-40	Technical Paper No. 40
TDR	Transfer of Development Rights
UDF	User-defined facilities
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
U.S. Multi-Hazards Flood Model	Hazus

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EXECUTIVE SUMMARY

The economic effects of flooding from extreme precipitation events are being experienced throughout the Great Lakes region. According to the Great Lakes Integrated Sciences and Assessments, "the frequency and intensity of severe storms has increased, and current models suggest that this trend will continue as the effects of climate change become more pronounced. More severe storms may have a negative economic impact due to resulting damages and increased costs of preparation, clean up, and business disruption."[1] The Federal Emergency Management Agency (FEMA) has estimated that nearly 40 percent of small businesses never re-open following a flooding disaster.[2]

The purpose of this study was to assess the economic benefits of green infrastructure (GI) as a method of reducing the negative effects of flooding in Duluth, Minnesota, and Toledo, Ohio. A secondary purpose of the study was to develop an analytical framework that can be applied in other communities to 1) consider and estimate predicted changes in future precipitation, 2) assess how their community may be impacted by flooding with increased precipitation, 3) consider the range of available green infrastructure and land use policy options to reduce flooding, and 4) identify the benefits (as well as co-benefits) that can be realized by implementing GI.

Green infrastructure can be broadly defined to include a variety of methods to manage water resources while providing benefits such as improved water quality. Such methods include land preservation as well as engineering approaches to maintain, restore, or create hydrologic functions that mimic natural processes. GI includes engineered systems (e.g., bioswales, green roofs, or permeable pavement) as well as preservation or enhancement of existing natural flood storage provided by wetlands, floodplains, and open space. In this project, GI focused on a suite of stormwater management practices designed to reduce flooding impacts by capturing, storing, and/or infiltrating precipitation. It is important to note that GI is just one method of reducing flooding and should be considered along with other policy, planning, and land use management strategies.

Two pilot projects were conducted to assess the benefits of GI in the 4,746-acre Silver Creek watershed in Toledo, Ohio, and the 4,275-acre Chester Creek watershed in Duluth, Minnesota. While both watersheds are of similar size and have a history of extreme flooding, they are very different in terms of population density, topography, land use, and the types of flood damages that occur. Thus, these two watersheds represent a range of flooding issues likely to occur within the Great Lakes region, and the methodology used here can be transferred to other communities facing similar challenges. Study steps included:

- Understanding the hydrology and hydraulics (H&H) of the watershed.
- Considering potential future changes in climate and in land use and potential impacts of those changes on H&H.
- Assessing damages associated with current and future flooding (baseline conditions).
- Considering challenges specific to the watershed and selecting GI options that can be implemented to reduce flooding over the study period.

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[1] Great Lakes Integrated Sciences and Assessments (GLISA). (2012). Fact Sheet: Climate Change in the Great Lakes Region. Retrieved from http://glisa.msu.edu/great_lakes_climate/background.php.

[2] The Center for Neighborhood Technology (CNT). (2013). The Prevalence and Cost of Urban Flooding: A Case Study of Cook County, IL.

- Assessing damages associated with improved future conditions (post-GI implementation).
- Comparing flood damages associated with baseline vs. improved conditions to determine the damage reductions that could result from GI implementation. These monetized avoided damages are expressed as economic benefits.

The project team worked closely with both communities to characterize existing flooding damages associated with extreme precipitation events, and to consider land use policy options and GI methods for reducing damages from these events. Based on preferred options identified by each community, the team modeled and assessed the benefits of reducing flooding through the implementation of GI. This report summarizes key findings and documents the study methodology.

ERG worked with the United States Army Corps of Engineers (USACE) Institute of Water Resources to assess each watershed using H&H models to estimate existing and future flooding, and with the Association of State Floodplain Managers (ASFPM) using FEMA's U.S. Multi-Hazards flood model (Hazus) to estimate existing and future potential losses associated with flooding (based on 2-, 5-, 10-, 25-, 50-, and 100- year storm events). Hazus estimates for this study included physical damage to buildings within the flood hazard area. It should be noted that additional damage occurs beyond Hazus estimates from such impacts as erosion and stream bank scouring, and from damages to assets other than buildings, such as roads, bridges, and other infrastructure. Thus, both the losses associated with flooding and the benefits of GI are likely to be greater than those captured in Hazus estimates.

The effects of climate change on future precipitation patterns were estimated using data from the U.S. Environmental Protection Agency's (EPA) Climate Resilience Evaluation and Awareness Tool (CREAT). Flooding modeled under current (2013) and future (2035) precipitation scenarios was coupled with current and future land use conditions to account for increased impervious surfaces that can further increase stormwater runoff volumes and peak flows. Next, flooding under current and future scenarios was modeled and associated damages were estimated using assumptions about additional flood storage that could be provided through the implementation of GI. Finally, the benefits of GI were estimated. The results of these analyses are presented below.

In Toledo's Silver Creek, economic losses from flooding increase by more than 30 percent in the future (2035) land use scenario with a 4.85 percent annual increase in precipitation, compared to existing conditions. If GI was implemented to reduce the peak discharge in Silver Creek by 10 percent (which corresponds to 31 acre-feet of flood storage under current conditions and 33 acre-feet of storage under future conditions), Hazus shows economic losses from flooding associated with a 100-year storm would decrease by 39 percent under current precipitation conditions and 46 percent under future precipitation conditions.

The economic flooding reductions shown by Hazus portray decreases in damage for a snapshot in time associated with one storm event of a particular size. In order to annualize the reduction in damages, economic losses from flooding for storms of all magnitudes were considered using expected annual damage (EAD) calculations.[3] Under this method, a 10 percent peak discharge reduction in Silver Creek decreases economic losses from flooding by 37 percent under current precipitation conditions and 41 percent under future precipitation conditions. These economic losses are based only on Hazus physical damage estimates to buildings and do not take into account damage to infrastructure, natural resources, business disruption, and other losses. Over a 20-year

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[3] EAD computations are used to account for the continuous nature of both storm severities and probabilities of occurring. In essence, EAD calculations smooth damages across discrete storm severities (e.g., 2-year, 5-year).

planning horizon, damage reductions (and hence economic benefits, based on Hazus only) equate to a total present value of about $700,000, or roughly $38,000 annually.

The cost of green infrastructure measures exceeds benefits when evaluated over the 20-year period. However, many green infrastructure measures, such as constructed wetlands, can be expected to provide benefits for far more than 20 years. When the time horizon is extended to 50 years, the costs remain constant but the benefits continue to grow until they exceed costs, providing evidence in favor of implementing green infrastructure measures. This demonstrates the importance of determining the appropriate time horizon when assessing benefits and conducting a benefit-cost analysis. It also demonstrates that a long-term perspective is essential to maximizing the benefits of investments in public infrastructure.

It is important to note that resource constraints for this study did not allow the evaluation of many benefits that are likely to be realized: reduction of damages to the contents of flooded buildings, reduction of damages to roads, bridges, water treatment plants, and other public infrastructure, and the beneficial services provided by the natural systems comprised in green infrastructure measures. Including these values would show that Toledo is likely to recoup investments in green infrastructure much sooner than indicated by the limited range of benefits assessed in this study.

In Duluth's Chester Creek watershed, economic losses from flooding increase by four percent in the future (2035) land use scenario with a 7.49 percent increase in future precipitation, compared to existing conditions. Property losses do not increase significantly because minimal future development is planned within the flood hazard area. If GI was implemented to reduce the peak discharge in Chester Creek by 20 percent (which corresponds to 76 acre-feet of flood storage under current conditions and 86 acre-feet of storage under future conditions), Hazus shows economic losses from flooding associated with a 100-year storm would decrease by 27 percent under current precipitation conditions and 16 percent under future precipitation conditions. The damage reduction is a lesser percentage under future conditions because development and precipitation are anticipated to increase in the future in Duluth.

When EAD calculations are used to consider storms of all magnitudes, a 20 percent peak discharge reduction in Chester Creek decreases the economic losses from flooding by 35 percent and 39 percent for building damages under current and future precipitation conditions, respectively.

Because flood damages to buildings under future scenarios are relatively minor in Duluth, the economic benefits of GI were evaluated across a wider spectrum of benefits than in Toledo. Other monetized benefits included increased recreational use of parks in the lower watershed (Chester Creek Park has historically incurred significant damage during extreme storm events); reduced near-stream land restoration costs; and reduced storm sewer maintenance and replacement costs. Damages to roads and bridges were not accounted for in this study. Over a 20-year planning horizon, damage reductions (and hence economic benefits) equate to a total present value of approximately $1.63 million, or roughly $89,000 annually with GI implementation. These estimates include assumptions concerning the time required to implement GI. The amounts will vary based on the assumptions used.

As in Toledo, the cost of green infrastructure measures exceeds benefits when evaluated over the 20-year period. The opposite is true when benefits are evaluated over a longer time horizon, showing that investments in green infrastructure yield benefits that exceed costs over in the long run. As with Toledo, not all benefit classes were considered in this analysis of green infrastructure in Duluth. Benefits that are likely to accrue, but that were not quantified, are the same as listed for

Toledo: reduction of damages to the contents of flooded buildings, reduction of damages to roads, bridges, water treatment plants, and other public infrastructure, and the beneficial services provided by the natural systems comprised in green infrastructure measures. Including these values would show that Toledo is likely to recoup investments in green infrastructure much sooner than indicated in by the limited range of benefits assessed in this study.

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1.0 INTRODUCTION

The economic, social, and environmental damage caused by flooding affects communities throughout the United States. According to NOAA National Weather Service, over the past 30 years the nation has averaged over $8 billion of economic damages and 89 deaths annually due to flooding.[4] Changing weather patterns and climate trends present challenges to predicting, managing, and mitigating flooding events. Community officials are increasingly interested in making the most cost-effective decisions about infrastructure investments and future land-use decisions to minimize flooding impacts and ensure a sustainable future for residents and businesses.

This study builds upon an analytical framework developed in a 2011 study by Resources for the Future[5] that focused on the Lower Fox River basin in Wisconsin. The Lower Fox River case study assessed land conservation as a landscape-scale GI option, looking at land conservation (versus developing those lands) as a means to mitigate flood damages. It provided a very useful framework to assess the costs and benefits of land conservation as a method of mitigating flood damages. The Lower Fox River study informed the method used to assess options to mitigate flooding challenges in Toledo, Ohio, and Duluth, Minnesota (see Figure 1).

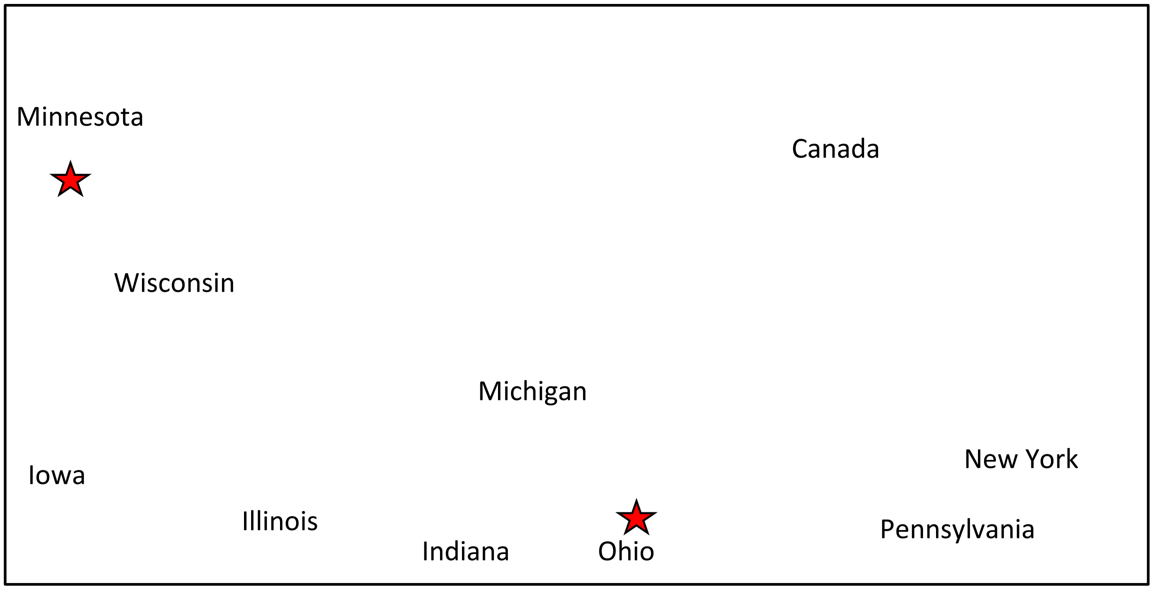

Figure 1. Study Locations

Chester Creek watershed in Duluth and Silver Creek watershed in Toledo were assessed to estimate the impacts of various flooding frequencies (e.g., 2-, 5-, 10-, 25-, 50-, and 100-year storm events) under multiple precipitation and land use scenarios. This assessment sought to answer the following questions:

1. What do flood damages look like under current land use and current precipitation conditions?

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[4] Hydrologic Information Center – Flood Loss Data. Retrieved from http://www.nws.noaa.gov/hic.

[5] Kousky, C. et. al. (2011). The Role of Land Use in Adaptation to Increased Precipitation and Flooding: A Case Study in Wisconsin's Lower Fox River Basin. Retrieved from http://www.rff.org/rff/documents/rff-rpt-kousky.etal.greatlakes.pdf.

2. What do flood damages look like under future land use and future precipitation conditions?
3. What do flood damages look like under current and future conditions if runoff is reduced with the implementation of GI?
4. Can GI implementation significantly decrease flood inundation and subsequently reduce flood damages?
5. What are the quantifiable benefits of reducing flood reduction with GI?
6. What are the co-benefits of GI (e.g., improved water quality, wildlife habitat, and increased property values)?

This report is organized as follows:

- **Section 1** provides an overview and background information.
- **Section 2** discusses the methodology used in Toledo and Duluth.
- **Section 3** presents a case study of Toledo, Ohio.
- **Section 4** presents a case study of Duluth, Minnesota.
- **Section 5** discusses lessons learned in this project.
- **Appendices A-H** contain detailed information referenced throughout the report.

1.1 Overview and Project Purpose

In order to mitigate flooding, it is important for communities to understand how precipitation currently impacts watersheds and how those impacts will change in the future as precipitation and land use also change. Future land use is important because development has the potential to increase flood damages by putting structures in harm's way and increasing runoff, which increases the footprint of harm's way. This study focused on assessing the flood storage capacity of a suite of engineered GI practices that mimic natural processes and are designed to reduce peak flows and improve water quality by capturing, storing and/or infiltrating precipitation where it falls (e.g., bioretention, vegetated roofs, permeable pavement). It provides a framework that communities can use to assess flooding within a watershed and inform decisions about the appropriate adaptive land use and GI options that are available to minimize flood damage.

Green Infrastructure (GI) - The term “green infrastructure” or “GI” in this study refers to stormwater management techniques that mimic natural hydrologic functions and incorporate the natural environment to treat stormwater where it falls. GI practices are constructed systems that mimic natural processes in an integrated network for the benefit of nature and people. Utilizing GI in community planning helps balance environmental and economic goals.

The outputs from the modeling scenarios were assessed in order to estimate how precipitation and future land use changes could affect the extent of flooding and resulting property damages in each community. The models were then re-run with assumptions made about implementation of GI to reduce flooding, and the benefits of mitigating future flooding scenarios were then calculated.

The methodology used in this study may be used in other communities asking the same questions. A summary of the assessment steps followed in this study is presented below:

Climate Prediction	• Determine the current and estimated future (2035) precipitation (Technical Paper No. 40 [TP-40] and EPA's CREAT were used in this study).
Land Use	• Determine the current and future land uses (data obtained from the cities).
Hydrology and Hydraulics	• Determine the resulting flood elevations associated with land use and precipitation assumptions (USGS regression equations and Hydrologic Engineering Center River Analysis System [HEC-RAS] were used in this study).
Flood Damage	• Estimate the cost of the building damage (FEMA's Hazus-MH was used in this study), and where information is available, estimate other flood damages.
Adaption Options	• Determine what can be done to minimize damages by providing flood storage through the implementation of GI.
Economics	• Estimate the costs and benefits of the chosen adaption options.

Physical building damage estimates using Hazus outputs were the primary economic measure of costs associated with flooding, as augmented by local data on other costs associated with past flooding events. When examining the flood damage reduction impacts of control measures, avoided or reduced costs are expressed as "benefits." Thus, reduced building damages estimated from Hazus were a significant benefit in this economic analysis. Where possible, other benefits were noted and, where data were available, quantified. For example, monetized benefits in Duluth included increased recreational use, reduced land restoration costs, and reduced storm sewer infrastructure costs. When assessing the economic impacts of GI in reducing flooding, it is important to note co-benefits, which are often difficult to monetize. Examples of co-benefits are things like public use of open space, improved air and water quality, increased property values, and improved wildlife and fisheries habitat. Not all benefits could be assessed due to data limitations and project scope. Therefore, estimated benefits presented in this study underestimate the true value of all potential benefits.

While the primary purpose of this study was to assess the economic benefits of GI as a method of reducing the negative effects of flooding in Duluth and Toledo, a secondary purpose was to develop an analytical framework that can be applied in other communities to 1) estimate predicted changes in future precipitation, 2) assess how their community may be impacted by flooding with increased precipitation, 3) consider the range of GI and land use policy options to reduce flooding, and 4) identify benefits and co-benefits that can be realized by implementing GI.

The analytical framework presented in this document is not a "one size fits all" solution to flood damage reduction, stormwater management, GI implementation, or benefit assessment. Rather, it outlines a process that communities can adapt to fit their individual needs and unique situations. Information is presented in a manner that will be useful to planners, engineers, policymakers, and the general public so they can utilize the information gained through these pilot projects to inform their own communities' policy-making and financial deliberations. The process outlined in this report is suggested as a first step that communities may take to begin to understand flooding at a watershed level. The outcomes of an assessment such as this one are to provide an "order of magnitude" assessment that may be built upon and refined as communities move from bigger picture analysis to site-specific solutions.

This study estimated average annualized benefits for a set of flooding events at selected intensities. Differences in benefits were evaluated under four assessment scenarios:

- **Scenario 1** - Current precipitation and current land use.
- **Scenario 2** - Future precipitation and future land use.
- **Scenario 3** - Current precipitation and current land use with increased flood storage via GI.
- **Scenario 4** - Future precipitation and future land use with increased flood storage via GI.

A comparison of the results of these four scenarios (see Table 1) allows us to estimate the degree to which GI can be expected to reduce flood losses. This information will enable local officials to be better informed regarding future investment decisions in order to cost-effectively reduce flooding in their communities.

Table 1. Assessed Flooding Scenarios

Scenario Number	Current Precipitation	Future Precipitation	Current Land Use	Future Land Use	Flood Storage using GI
1	✓		✓		
2		✓		✓	
3	✓		✓		✓
4		✓		✓	✓

Important Notes About This Project:

- GI includes a wide variety of methods that could be used to manage water resources, and in this project a subset of GI most viable in Toledo and Duluth was assessed.
- Hazus can be used to estimate a wide variety of damages, and in this project Hazus was used to only estimate damage to buildings.
- Benefits can include a wide range of social, environmental, and economic benefits; in this project, benefits were calculated using Hazus (as narrowly defined above) and, in the case of Duluth, some additional benefits for which cost estimates could be provided. Other benefits and co-benefits were not monetized (for a list of potential co-benefits see Appendix B).
- A cost-benefit analysis was not conducted in this study. While the cost per unit volume of flood storage was estimated and provided for GI practices (see Appendix C), the study team lacked the level and sequencing of implementation needed to estimate costs and thus to compare costs to benefits.
- This analysis provides planning-level estimates that require more detailed and site-specific engineering design in order to cost out the GI alternatives included in this report.

This study represents an important opportunity to demonstrate the benefits of GI in the face of increased precipitation and more severe flooding events. The assessments in this study were performed for watersheds that constitute only a small portion of the cities of Duluth and Toledo. Expanding the study area would increase complexity, but provide a more community-wide representation of flooding issues, options for flood mitigation, and economic analysis. For example, assessing costs and benefits of flooding adaptation options across a larger geographic area would offer economies of scale for reducing implementation costs, provide a more robust array of trade-off considerations, and enable a fuller suite of options to be considered, including community-wide approaches such as increasing open space in flood-prone areas and shifting development density away from flood hazard areas via re-zoning, transfer of development rights, and other incentive-based methods to enhance resilience, long-term sustainability and economic growth. Ideally, flood mitigation strategies would be incorporated into a community-wide sustainability plan.

Flooding and stormwater management practices are constantly evolving, and in no way are the GI and land use policy options presented in this study meant to represent the only acceptable way to sustainably reduce flooding. NOAA CSC encourages the development and implementation of innovative flood reduction strategies that both reduce flooding damages and provide community co-benefits associated with increased levels of ecosystem services.

1.2 Climate Change

Extreme rainfall events and flooding have increased in frequency and intensity during the last century in the Midwestern United States.[6] According to the Intergovernmental Panel on Climate

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[6] U.S. Global Change Research Program (USGCRP). (2013). Draft National Climate Assessment, Chapter 18: Midwest, V 11 Jan 2013. Retrieved from http://ncadac.globalchange.gov/download/NCAJan11-2013-publicreviewdraft-chap18-midwest.pdf.

Change (IPCC), global temperature rose by approximately 1.33°F during the last century.[7] In 2012, the United States endured 11 extreme weather events that each had more than $1 billion in economic losses.[8] The United States experienced its warmest 12-month period from August 2011 to July 2012.[9] Many factors contribute to climate change (see Figure 2), which is why it is challenging to predict and estimate the specific climate changes that will impact a geographic area.

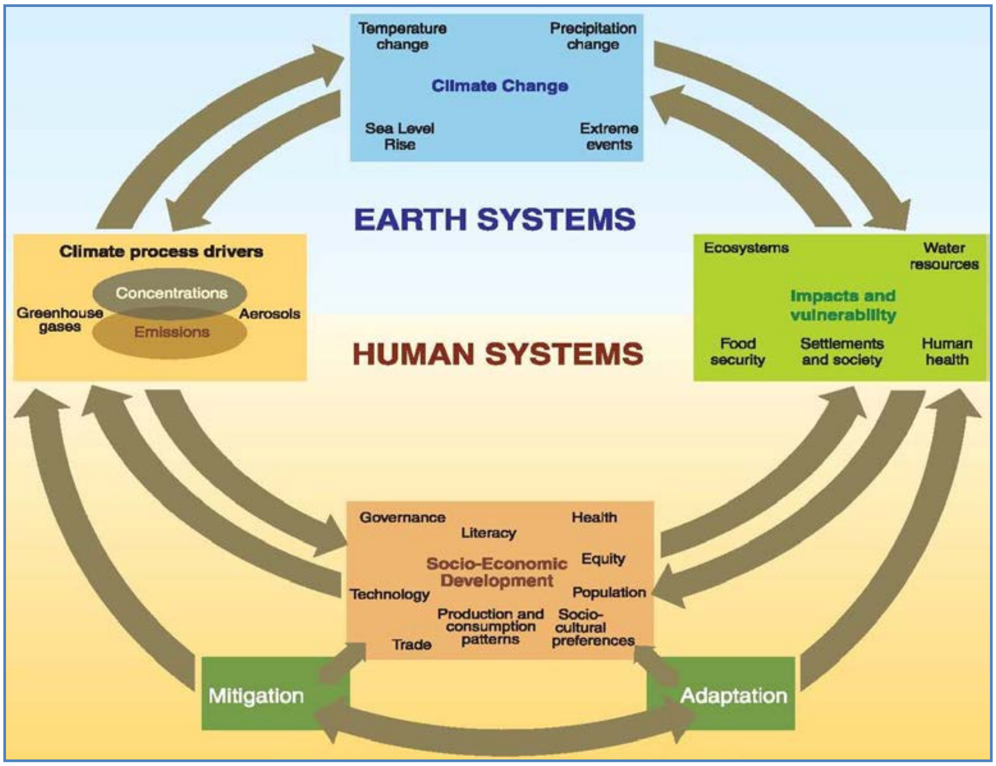

Figure 2. Climate Change Drivers, Impacts, and Responses[10]

Since 1990, the Great Lakes region has experienced a five-to-ten percent increase in precipitation.[11] Average temperatures in the Great Lakes region are projected to increase by approximately two to eight degrees Fahrenheit (°F) by the end of the century (2020–2099).[12] Many climate scientists

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[7] Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds). (2007). Intergovernmental Panel on Climate Change (IPCC). Fourth Assessment Report. Working Group I: The Physical Science Basis. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[8] NOAA National Climatic Data Center. Billion-Dollar Weather/Climate Disasters. Retrieved from http://www.ncdc.noaa.gov/billions/.

[9] NOAA National Climatic Data Center. State of the Climate: National Overview for Annual 2012. (2012). Retrieved from http://www.ncdc.noaa.gov/sotc/national/2012/13.

[10] Pachauri, R.K. and Reisinger, A. (eds.). (2007). Intergovernmental Panel on Climate Change. Synthesis Report Summary for Policymakers.

[11] Kling, G.W., K. Hayhoe, L.B. Johnson, J.J. Magnuson, S. Polasky, S.K. Robinson, B.J. Shuter, M.M. Wander, D.J. Wuebbles, D.R. Zak, R.L. Lindroth, S.C. Moser, and M.L. Wilson. (2003). Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystems. Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C.

[12] Wuebbles, Donald J., Katharine Hayhoe, and Julia Parzen. (2010). Introduction: Assessing the effects of climate change on Chicago and the Great Lakes. Journal of Great Lakes Research 36.sp2 1-6.

agree that the Great Lakes region will experience an increase in the frequency of intense precipitation events.[13]

Projections of average annual precipitation are less certain than temperature projections.[6] Changes in precipitation may include increases in the amount of winter and spring precipitation with projected increases of about 10 percent by mid-century and 20 to 30 percent by the end of the century relative to current seasonal levels.[12]

Increases in intense precipitation, accompanied by erosion and declining water quality, could likely result in negative impacts on public infrastructure, private property, the economy, and human health.[6] The magnitude of flooding impacts from projected changes in precipitation will vary based on local conditions and include both physical and economic effects. Economic effects are often clouded by other variables such as increased wealth and development, so that the same physical effects cause more damage as areas develop.

The land use strategies considered in this study reflect an approach that aims to increase resilience to future flood events, specifically strategies for adapting to stormwater runoff impacts from an increase in the frequency and intensity of precipitation events.

1.3 The Connection between Stormwater Management and Flooding

Flooding occurs when precipitation accumulates faster than it can be infiltrated, evaporated, transpired, stored, or conveyed to receiving waters. Flooding occurs naturally. Floodplain areas, if left in their natural state, function to store and gradually release flood flows, which re-nourish floodplains and bordering wetlands with sediment and other nutrients. Development can increase flood losses because new structures are sometimes placed directly in harm’s way if they are built in flood-prone areas. Additionally, development outside the floodplain can reduce the natural systems’ ability to moderate flooding. Development increases flooding when pervious, vegetated land is replaced with impervious surfaces (e.g., pavement, buildings). This reduces evapotranspiration and prevents precipitation from slowly infiltrating into the soil and recharging groundwater, rivers, and streams. Impervious surfaces increase stormwater runoff volumes (Figure 3.), velocities, and peak discharges.

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[13] Patz, JA, Vavrus S, Uejio C, McClellan S. (2008). Climate Change and Waterborne Disease Risk in the Great Lakes Region of the US. American Journal of Preventive Medicine; 35(5):451–458.

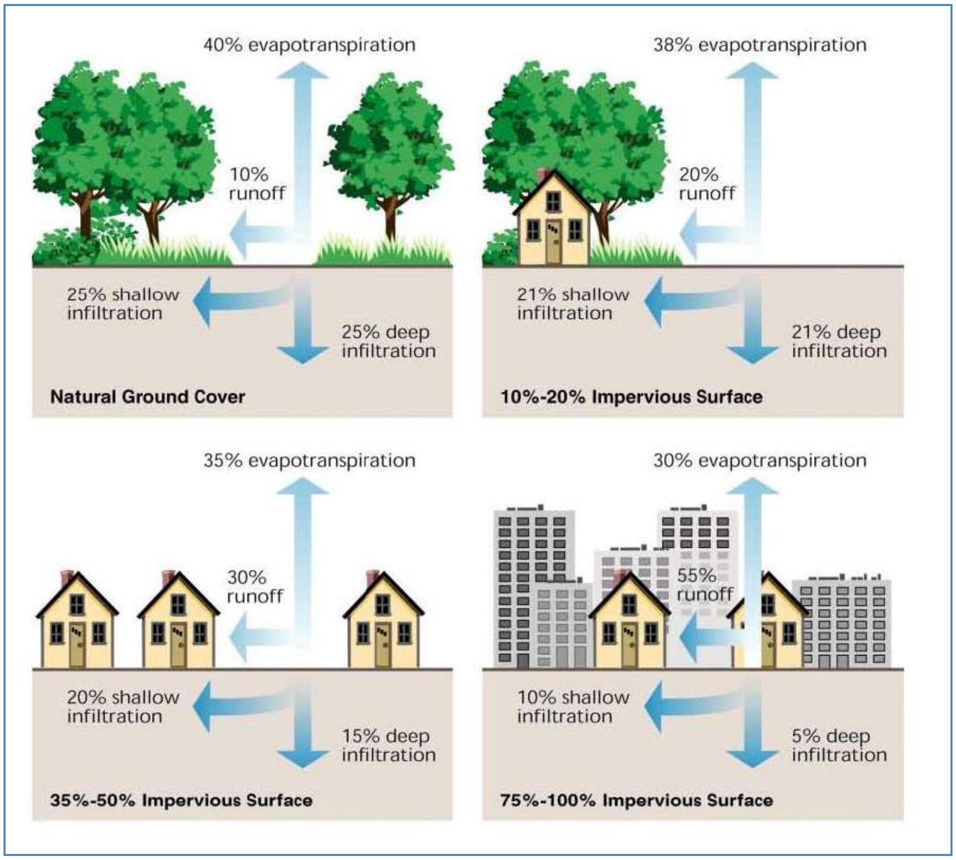

Figure 3. Correlation between Runoff and Impervious Surfaces[14]

Other factors influence flooding, both positively and negatively (see Figure 4). One of the main factors that impacts flooding is stormwater runoff. Stormwater runoff, which increases as a function of impervious surface, not only causes flooding (both peak flow and total volume of stormwater runoff), but can also affect water quality by increasing the temperature of receiving water, as well as sediment, pathogens, and nutrient loads. Urban flooding can occur due to overbank flooding or when stormwater overwhelms drainage systems and ends up in basements, backyards, and streets.[2]

Overbank Flooding – Flooding that occurs when water overtops the banks of waterways.

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[14] Federal Interagency Stream Restoration Working Group (FISRWG). (1998). Stream Corridor Restoration: Principles, processes, and Practices. PB98-158348LUW.

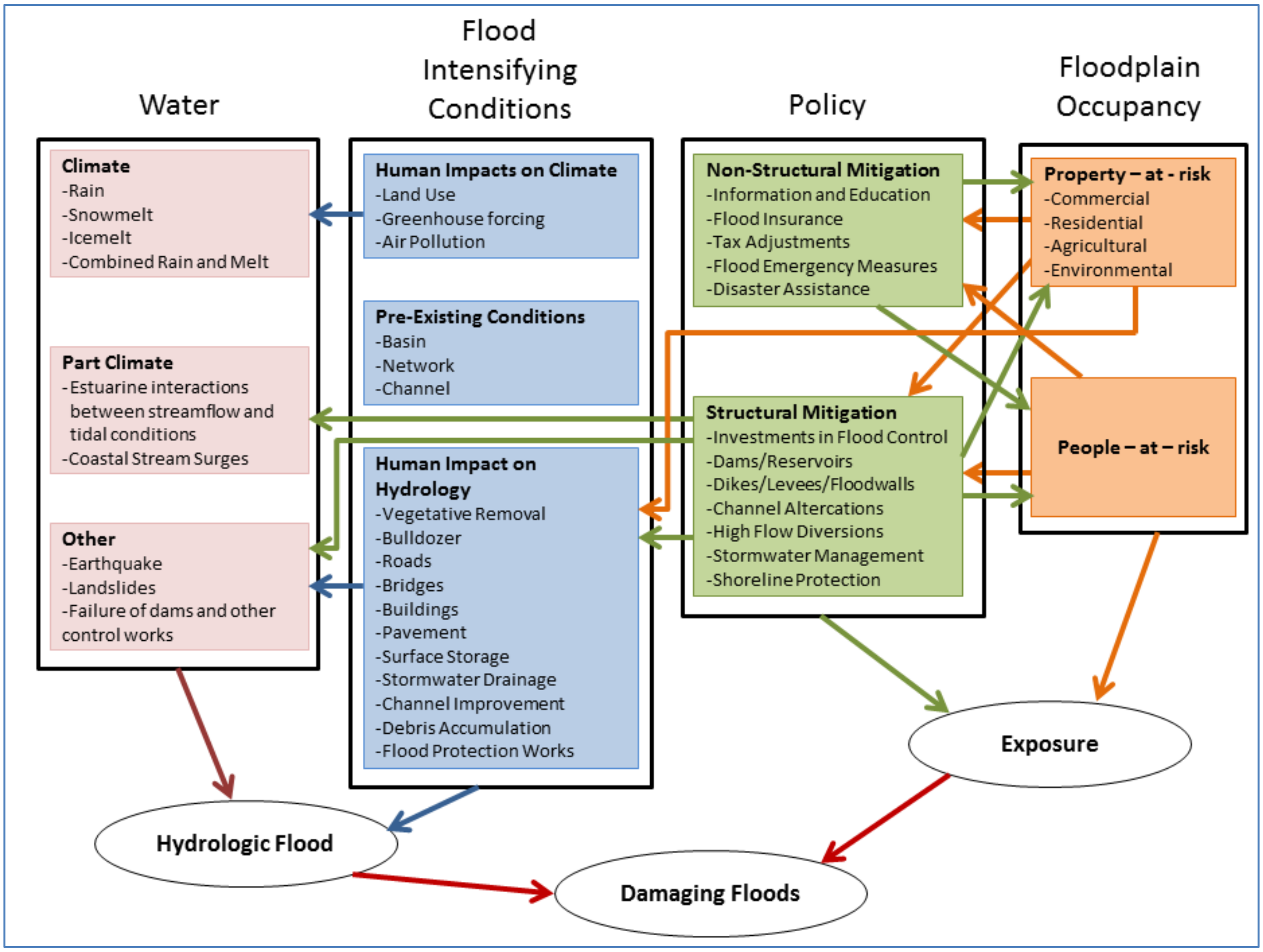

Figure 4. Factors that Influence Flooding[15]

Hydrology – The runoff volume, peak discharge, infiltration, and evapotranspiration (evaporation and transpiration) rates that exist on a site. Predevelopment hydrology refers to site conditions prior to human-induced development. Post-development hydrology refers to site conditions after human-induced development.

Post-development hydrology is often very different from predevelopment hydrology. When watershed hydrology changes due to development, runoff is increased and floodplains may not be able to contain the increase in stormwater runoff. Consequently, flood elevations can increase and adjacent low-lying areas can become more flood prone. This situation is exacerbated when development occurs within the floodplain and adjacent areas because natural flood storage capacity is displaced.

According to the EPA's Clean Watersheds Needs Survey Report to Congress in 2008, it is estimated that $42.3 billion is needed for stormwater capital

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[15] Pielke, R. and Downton, M. (2000). Precipitation and Damaging Floods: Trends in the United States, 1932–97. *Journal of Climate*: Vol. 13, No. 20, pp. 3625–3637. Retrieved from http://sciencepolicy.colorado.edu/admin/publication_files/resource-60-2000.11.pdf.

costs in the United States over the next 20 years.[16] It is important that GI is considered along with other long-term investments as communities look to the most cost-effective and sustainable approaches to address their stormwater needs, especially in the face of climate change. In this study, GI focused on a suite of stormwater management practices designed to reduce peak flows and mimic natural ecological processes by storing and/or infiltrating precipitation where it falls.

1.4 Green Infrastructure Stormwater Management Practices

Historically, communities attempted to manage drainage and flooding by implementing conventional engineering stormwater management approaches. These conventional stormwater management approaches are often referred to as "gray" infrastructure and include culverts, catch basins, levees, pumps, and storage tunnels. Conventional gray infrastructure approaches quickly route stormwater away from developed areas and do not maintain predevelopment hydrology. Gray infrastructure manages stormwater by reducing the peak discharge of runoff (i.e., controlling how fast stormwater is released), but does not focus on reducing stormwater runoff volumes or retaining runoff on site.

Gray Infrastructure – Traditional stormwater management practices that do not mimic natural hydrologic conditions. Gray infrastructure relies on structural engineering designs such as curbs, gutters, drainage ponds, culverts, levees, and storage tunnels.

GI incorporates the natural environment and constructed systems in an integrated network to provide multiple benefits and support resilient communities (see Figure 5). GI is designed to reduce the effects of development on stormwater by maintaining or engineering some of the flood reduction functions of predevelopment conditions. This type of sustainable stormwater management often includes "low impact development" (LID) methods to reduce runoff from impervious surfaces. Unlike gray infrastructure, GI strategies take advantage of natural systems, designed to mimic predevelopment hydrology and reduce runoff at its source. Engineered GI planned in conjunction with watershed-scale conservation of existing natural lands (e.g., wetlands, floodplains, forests) can help communities balance environmental and economic goals. GI provides economic co-benefits, including aesthetics and a range of ecosystem benefits beyond flood protection such as water quality and wildlife habitat.

In most communities where gray infrastructure is already in place, there are opportunities to design for or "retrofit" GI during infrastructure replacement and capital improvement projects. GI options are gaining widespread support as a credible approach that communities can use to manage stormwater sustainably and provide co-benefits. Figure 5 shows the wide range of benefits that could be realized from implementing a few selected types of GI techniques.

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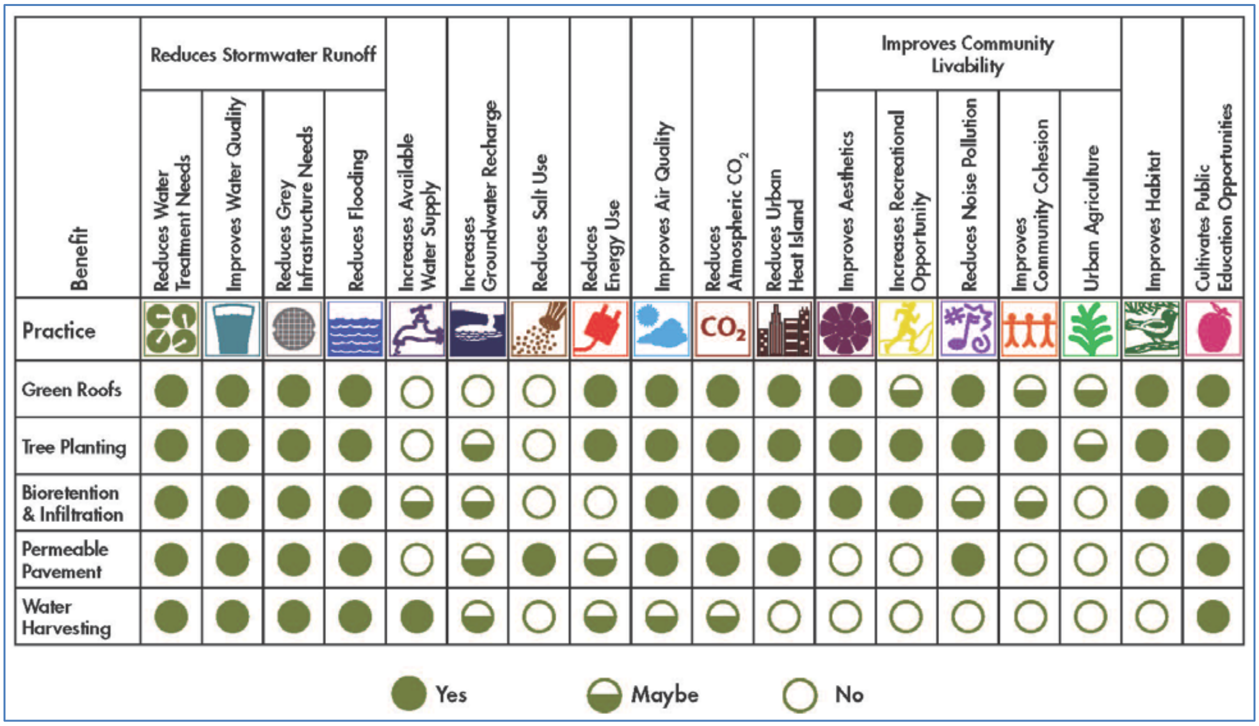
[16] U.S. Environmental Protection Agency (EPA) Office of Water Management. (2012). *Clean Water Needs Survey 2008 Report to Congress*. Retrieved from http://water.epa.gov/scitech/datait/databases/cwns/upload/cwns2008rtc.pdf.



Benefit	Reduces Stormwater Runoff											Improves Community Livability						
	Reduces Water Treatment Needs	Improves Water Quality	Reduces Grey Infrastructure Needs	Reduces Flooding	Increases Available Water Supply	Increases Groundwater Recharge	Reduces Salt Use	Reduces Energy Use	Improves Air Quality	Reduces Atmospheric CO_2	Reduces Urban Heat Island	Improves Aesthetics	Increases Recreational Opportunity	Reduces Noise Pollution	Improves Community Cohesion	Urban Agriculture	Improves Habitat	Cultivates Public Education Opportunities
Practice										CO_2								
Green Roofs	●	●	●	●	○	○	○	●	●	●	●	●	◒	●	◒	◒	●	●
Tree Planting	●	●	●	●	○	◒	○	●	●	●	●	●	●	●	●	◒	●	●
Bioretention & Infiltration	●	●	●	●	◒	◒	○	○	●	●	●	●	●	◒	◒	○	●	●
Permeable Pavement	●	●	●	●	○	◒	●	◒	●	●	●	○	○	●	○	○	○	●
Water Harvesting	●	●	●	●	●	◒	○	◒	◒	◒	○	○	○	○	○	○	○	●

● Yes ◒ Maybe ○ No

Figure 5. The Benefits of Selected Green Infrastruture Practices[17]

The following Sections 1.4.1 through 1.4.7 of this report discuss several of the GI practices that were evaluated in this assessment. While a wide array of practices exist, this project focused only on those considered viable by the communities. Table 2 presents a listing of GI practices that were presented and discussed at Toledo and Duluth community meetings. In addition to these methods, land use policy options were also presented and discussed, including updating stormwater ordinances, using land-use tools such as zoning and Transfer of Development Rights (TDR) to shift development away from flood-prone areas to areas more suitable for development, and land preservation and restoration. See Appendix E for a more complete list of GI practices.

Table 2. Green Infrastructure Practices Discussed at Community Meetings

Type of Green Infrastructure	Benefits
Permeable/Porous Pavement • Permeable pavers, porous asphalt, pervious concrete, porous concrete	• Reduce runoff quantity during storm events. • Can potentially reduce the need for road salt use. • Improve water quality from underground media filtration.
Rainwater Harvesting/Storage • Rain barrels, cisterns, underground tanks, added flow-control valves	• Require minimal space and thus suited for urban residential, commercial, and/or industrial areas. • Reduce water demand. • Reduce runoff volume to conventional stormwater facilities, especially with flow-control valves.

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[17] Center for Neighborhood Technology (CNT) and American Rivers. (2010). *The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits*.

Type of Green Infrastructure	Benefits
Roof Systems • Blue roofs, extensive green roofs, intensive green roofs	• Green and blue rooftops reduce stormwater peak flow and runoff volume. • Green roofs provide additional pollutant removal through uptake and filtering. • Both can be used on many types of buildings. • Green roofs can be designed for public access.
Infiltration Systems • Infiltration trenches/basins, grass strips, biofilters/sand filters	• Improve stormwater quality. • Provide temporary storage and help to reduce flooding during small storms. • Promote infiltration and groundwater recharge.
Bioretention Systems • Bioretention cells, tree filters, stormwater planters, rain gardens, bioswales, stormwater tree trenches	• Maintain water balance and provide groundwater recharge. • Promote pollutant uptake through vegetation. • Utilize existing green space to serve a functional purpose while keeping aesthetic appeal.
Constructed Wetlands • Shallow marsh wetlands, extended detention wetlands, and gravel wetlands	• Improve water quality through pollutant removal. • Reduce peak discharges. • Provide flood control for higher magnitude storms. • Subsurface gravel wetlands provide year-round stormwater treatment in colder climates.
Wet and Dry Ponds • Wet ponds are similar to constructed wetlands but often don't include the wetland vegetation and differ in depth. • Dry ponds offer temporary storage after storm events and drain almost completely after a specified period of time.	• Provide flood control by including additional flood detention storage. • Reduce peak discharges.

1.4.1 Bioretention

Bioretention is an adapted landscape feature that provides onsite storage and infiltration of collected stormwater runoff. Stormwater runoff is directed from surfaces to a shallow depression that allows runoff to pond prior to infiltration in an area that is planted with water-tolerant vegetation. As runoff accumulates, it will pond and slowly travel through a filter bed (pictured on the right) where it either infiltrates into the ground or is discharged via an underdrain. Small-scale bioretention areas are often referred to as rain gardens. A bioswale (below) along a roadway is also a bioretention practice. In locations with low infiltration rates, underdrains can be used to collect runoff at the bottom of the filter bed and discharge the treated runoff to another GI practice or storm sewer system. Allowing runoff to filter through soil removes pollutants and reduces peak discharges, which mitigates flooding.[18, 19]

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[18] Virginia Department of Conservation and Recreation (DCR). (2011). Virginia DCR Stormwater Design Specification No. 9: Bioretention. Retrieved from http://vwrrc.vt.edu/swc/NonProprietaryBMPs.html.

1.4.2 Blue Roof

A blue roof is designed to hold up to eight inches of precipitation on its surface or in engineered trays. It is comparable to a vegetated roof without soil or vegetation. After a storm event, precipitation is stored on the roof and discharged at a controlled rate. Blue roofs greatly decrease the peak discharge of runoff and also allow water to evaporate into the air prior to being discharged.[20] Precipitation discharge is controlled on a blue roof through a flow restriction device around a roof drain. The water can either be slowly released to a storm sewer system or to another GI practice such as a cistern or bioretention area.[21, 22]

1.4.3 Permeable Pavement

Permeable pavement includes both pavements and pavers with void space that allow runoff to flow through the pavement (pictured left). Once runoff flows through the pavement, it is temporarily stored in an underground stone base prior to infiltrating into the ground or discharging from an under drain. Permeable pavers are highly effective at removing heavy metals, oils, and grease in runoff. Permeable pavement also removes nutrients such as phosphorous and nitrogen. Soil and engineered media filter pollutants as the runoff infiltrates through the porous surface. The void spaces in permeable pavement surfaces and reservoir layers provide storage capacity for runoff. All permeable pavement systems reduce runoff peak volume.[23, 24]

1.4.4 Underground Storage

Underground storage systems vary greatly in design. Underground storage systems detain runoff in underground receptacles that slowly release runoff. Often the underground receptacles are culverts, engineered stormwater detention vaults, or perforated pipes. One of the benefits of underground storage is that it does not take up additional surface area and can be implemented beneath roadways, parking lots, or athletic fields. Underground storage systems are typically designed to store large volumes of runoff and therefore can have a significant impact in reducing flooding and peak discharges.

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[19] Bioswale Photo Source: www.epa.gov.
[20] Beyerlein,D., Brascher, J., and White, S. (2005). Green Roof Hydrology.
[21] Hawkins, K. (2010). BLUE is the new Green. Retrieved from http://hpigreen.com/tag/blue-roof/.
[22] Blue Roof Photo Source: Hazen and Sawyer.
[23] Virginia Department of Conservation and Recreation (DCR). (2011). Virginia DCR Stormwater Design Specification No. 7: Permeable Pavement.
[24] Permeable Pavement Photo Source: Horsley Witten Group, Inc.

1.4.5 Stormwater Tree Trench

A stormwater tree trench is a row of trees that is connected by an underground infiltration structure. At the ground level, trees planted in a tree trench do not look different than any other planted tree. Underneath the sidewalk, the trees sit in a trench that is engineered with layers of gravel and soil that store and filter stormwater runoff. Stormwater tree trenches provide both water quality and runoff reduction benefits.[25, 26]

1.4.6 Retention Pond

A retention pond is one of the earliest prototypes of GI, and is now considered a more traditional type of stormwater infrastructure because it has been integrated into gray infrastructure design. It is an engineered stormwater basin designed to store runoff and release it at a controlled rate while maintaining a level of ponded water. Pollutants and sediment loads are reduced as the runoff is retained in the basin. Retention ponds are a very common stormwater management practice and may be designed with sustainable elements to increase water quality and decrease peak discharges.[27] Vegetated forebays may be added to increase sediment removal as well as provide habitat. Another enhancement to traditional stormwater retention ponds is the addition of an iron-enhanced sand filter bench that removes dissolved substances such as phosphorus from runoff.[28]

1.4.7 Extended Detention Wetland

Extended detention wetlands, such as the one shown in the figure on the right, may be designed as a flood mitigation strategy that also provides water quality and ecological benefits. Extended detention wetlands can require large land areas, but come with significant flood storage benefits. Extended detention wetlands can be created, restored (from previously filled wetlands), or enhanced existing wetlands. Wetlands typically store flood water during a storm and release it slowly, thereby reducing peak flows. An extended detention wetland allows water to remain in the wetland area for an extended period of time, which provides increased flood storage as well as water quality benefits.[29] Extended detention wetlands are distinct from preservation of existing wetlands, but the two practices often are considered together as part of a watershed-based strategy.[30]

1.5 Economics of Green Infrastructure

In this analysis, the amount of reduced damages associated with flood reduction strategies is represented as "benefits." First the economic impact of flooding is estimated, and then the amount

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[25] Philadelphia Water Department. Green Stormwater Infrastructure Tools: Stormwater Tree Trench. Retrieved from http://www.phillywatersheds.org/what_were_doing/green_infrastructure/tools.

[26] Stormwater Tree Trench Photo Source: Filterra.

[27] Sustainable Cities Institute. Stormwater Management: Retention Ponds. Retrieved from http://www.sustainablecitiesinstitute.org/view/page.basic/class/feature.class/Lesson_Retention_Ponds_Overview

[28] Minnesota Pollution Control Agency. Iron enhanced sand filter combined. Retrieved from http://stormwater.pca.state.mn.us/index.php/Iron_enhanced_sand_filter_combined.

[29] U.S. EPA. Stormwater Wetland. Retrieved from http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=74.

[30] Extended Detention Wetland Photo Source: Horsley Witten Group, Inc.

those impacts would be reduced with the implementation of GI is estimated. The difference between those two numbers--the dollar value of avoided damages--is considered the “benefit.” In Toledo, only benefits from Hazus (i.e., building damages) are assessed. Additional data was available in Duluth that allowed benefits beyond avoided building damage to be assessed. The following benefits are monetized in this report:

1. Reduced physical building damages (Duluth and Toledo).
2. Increased recreational use (Duluth).
3. Reduced land restoration costs (Duluth).
4. Reduced stormwater infrastructure costs (Duluth).

Annual benefits are assessed and the present value (PV) of these benefits is estimated for a 20-year period. The PV calculation discounts benefits in future years and aggregates the benefits across years. The PV represents the current value of future benefits. Many GI practices provide benefits beyond 20 years, so assessing benefits for a 20-year period reduces the PV in many instances. Expanding the assessment out to 50 years (as considered in the analysis) gives a more accurate representation of benefits that GI practices provide throughout their lifespan.

Additionally, GI practices and policies provide numerous benefits that are not easily monetized or even tangible in some cases. Placing a value on benefits such as habitat, ecosystems, green space, aesthetics, connection with nature, etc. is difficult and often very subjective. The monetized benefits summarized in this study are based on tangible costs only. The true PV of implementing GI is much greater than those monetized here.

2.0 METHODOLOGY

Community engagement was a strong underpinning of this study. The study team worked closely with community partners to:

- Obtain community input on study design and available data.
- Develop selection criteria and choose a watershed to assess.
- Understand the nature and extent of past flooding.
- Determine current and future precipitation.
- Model the H&H of the watershed under existing and future precipitation scenarios.
- Incorporate community information on existing and future land use and zoning to examine impacts of future land use on flooding.
- Estimate the physical building damage and incorporate other flood damage costs provided by the community (where available).
- Identify preferred GI to assess.

2.1 Community Engagement

The project team visited each community to present background information about the goals of the study and to determine what data, studies, and other resources were available to inform the analysis. The purpose of the community meeting was to hear about issues of concern and the needs for translating results to community action. The following questions were posed to the participants during the initial meeting and discussed as a group (for a list of participants see Appendix F):

1. How are heavy rainfall and flooding events currently affecting your community and how are you dealing with those impacts?
    - Describe the issues and concerns associated with heavy rainfall in your community.
    - Are there areas that are especially susceptible or have been impacted in the past?
2. What would successful outcomes of this project look like to you?
    - How would you like to use the assessment results?
    - Are there plans/projects/programs/people that you would like to see influenced from the outcomes?
3. What kinds of resources and activities would help you use project results in your community to achieve success?
    - What products would you like to see?
    - What type of help do you need to translate, communicate, and use the information from the assessment in your community?

Prior to the community meetings, stakeholders provided input on candidate watersheds for the study. The short list of watersheds was discussed further at the community meetings to narrow down a watershed study area. The following factors were discussed for each proposed watershed:

- Community interest.
- Percent developed/urban.
- Vulnerable population present in this area.
- Developable land and percent planned for future development.
- Current/planned restoration projects.
- Economic factors (recreation, ecological, fisheries, scenic, other public values).
- Publically owned land or potential public easements (land price/land value).
- Historic flood damage.
- Water quality impacts from flooding (e.g., high sediment load, combined sewer overflows (CSO), loss of habitat).
- Availability of local H&H models and data.
- Subsurface geology (is there infiltration capacity amenable to green infrastructure?).

During the community meeting, the project team gathered information about the availability of the following types of data within the watersheds of interest:

- Physical characteristics.
- Land use types.
- Current/planned development, zoning, regulations, and projects going on in study area.
- Community practices for stormwater.
- Watershed boundaries, stream flow, soils, and flood elevation information.
- Existing H&H models and water quality data.
- Tax forfeited parcels.
- Historic flood damage data.

Once these characteristics were discussed and the candidate watersheds were narrowed down, the following primary selection criteria were used to choose one watershed:

- Community preference.
- Availability of data.
- Presence of severe flooding events/current damages for baseline conditions.
- Opportunities for solutions.
- Small enough area to assess, but large enough area to show measurable change between the scenarios.

Additionally, the project team toured the watersheds to gain a firsthand knowledge of the factors discussed during the community meeting. The information obtained from the community discussions and watershed tour was used to ensure that the unique challenges and community-specific concerns relating to flooding were understood prior to conducting the assessment.

2.2 Precipitation and Land Use Scenarios

This study assessed the impacts of changes in precipitation and land use on flooding damages. The planning horizon was the year 2035. This year was chosen because it provides an approximately 20-year outlook, which is useful for planning. EPA's CREAT also benchmarks future precipitation values for 2035.

Each assessment scenario modeled conditions for a specific design storm (also referred to as a storm event). Examples of a design storm are the 1-year, 24-hour storm event, or the 100-year, 24-hour storm event. The year designation (i.e., 1-year) is a recurrence interval and indicates the probability that a storm of a certain size will occur during any given year. A 1-year storm has a 100 percent chance of occurring in any given year. A 100-year storm has a 1 percent chance of occurring in any given year.[31] The hour designation (i.e., 24-hour) is the recurrence interval duration. The design storms for this study were chosen based on information from the communities; the communities considered several factors, such as when they start seeing damages.

2.3 Modeling Overview

The first modeling step in this study was to use historical climate data from TP-40 titled "Rainfall Frequency Atlas of the United States," in addition to projected climate data from EPA's CREAT, to characterize existing and expected future precipitation.[32] This information was used as an input into the USGS regression equations for each region, which provide peak flow estimates for various storm events. These peak flows were used as an input for the one-dimensional hydraulic model HEC-RAS to characterize current and future flood depths. Physical attributes of the watershed such as the slope of the watershed, the gradient of the stream, and the imperviousness of the land are taken into account when developing input to both models. Output from the HEC-RAS model was used to develop two-dimensional "depth grids" that indicate depth of flooding for a 20-ft x 20-ft square area (the entire watershed was divided into 20-ft x 20-ft grids to aid in flood characterization). The H&H inputs relating to available flood storage were changed in order to produce revised depth grids for the assessment scenarios that consider the implementation of GI and adaptive land use. Once the flood depth grids were established, flood damages were assessed using FEMA's Hazus to estimate flood damages (see Figure 6 and Figure 7).

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[31] Parzybok, T., Clarke, B., and Hultstrand, D. (2011). Average Recurrence Interval of Extreme Rainfall in Real-time. Retrieved from http://www.earthzine.org/2011/04/19/average-recurrence-interval-of-extreme-rainfall-in-real-time/.

[32] The USGS regression equations used in this analysis called for precipitation values from National Weather Service TP-40, published in 1961. More recent data (e.g., Atlas 14) are available for many communities and may be appropriate for use in future studies. Atlas 14 was not available for Minnesota at the start of this study, which led to the selection of TP-40 as the source of precipitation data.

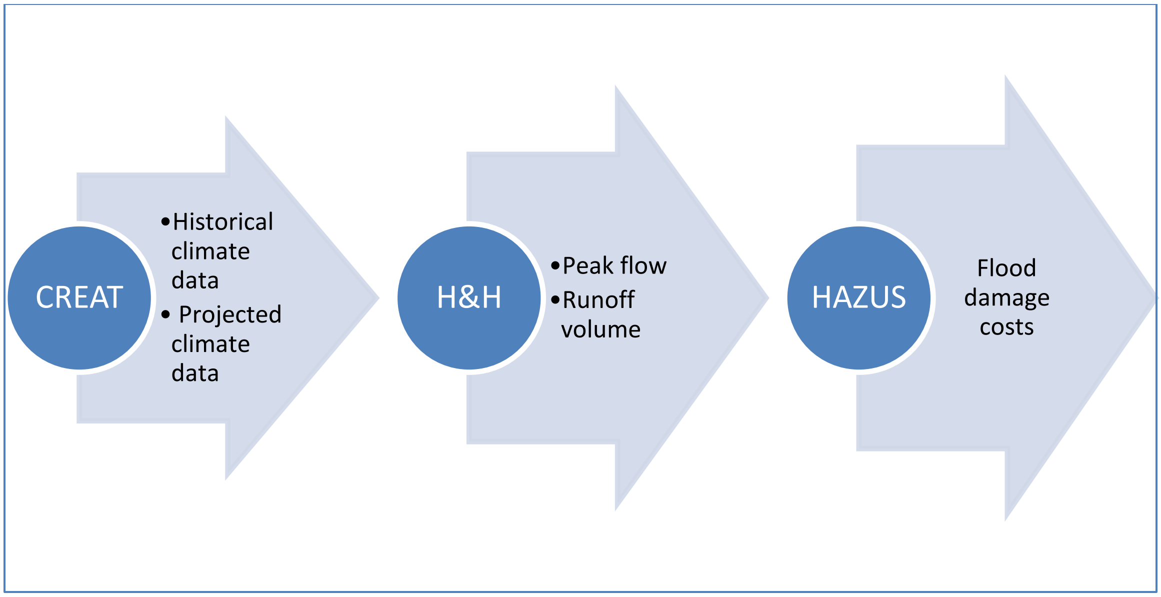

Figure 6. Study Models

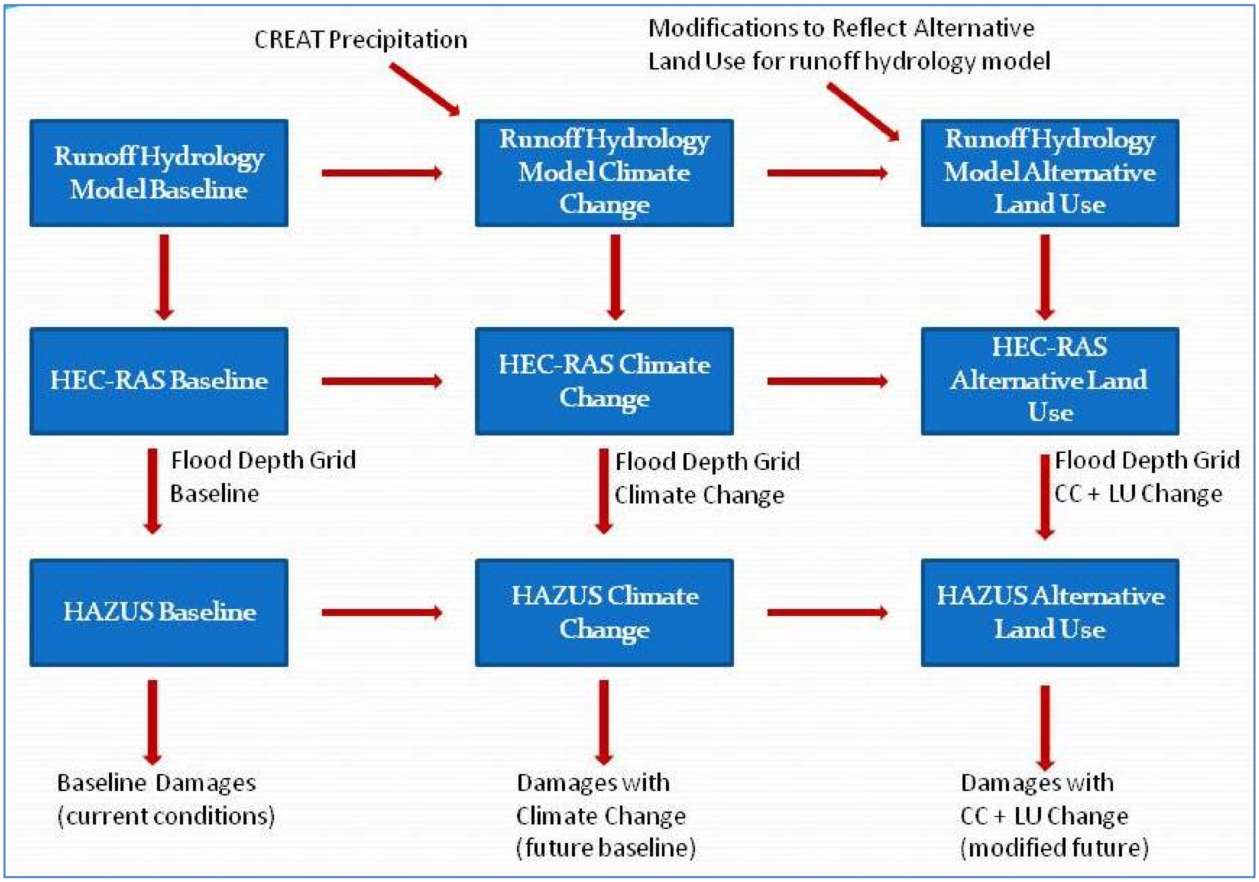

Figure 7. Study Models and Outputs

2.3.1 CREAT

In order to estimate future precipitation conditions in Toledo and Duluth, future climate scenarios were examined using CREAT (version 2.0). Precipitation data were extracted from CREAT and used to provide downscaled climate projections for precipitation that were used as inputs for the H&H models. CREAT was chosen for this study because it provides local, downscaled climate data, specifically future projections of precipitation event frequency.

All model runs used to develop future climate scenarios within CREAT use the A1B emissions scenario from the IPCC *Special Report on Emissions Scenarios* (SRES). The IPCC SRES considers alternative future developments, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions. The A1B scenario assumes rapid economic growth, a peak mid-century global population, and rapid introduction of new and more efficient technologies.[10] Refer to Figure 8 for a graphic of the difference in global surface warming over time per scenarios in IPCC SRES. Projections from general circulation models (GCMs) that consider a different emissions scenario may produce differing results than the CREAT data used in this study. As illustrated by the green line in Figure 8, A1B is generally regarded as a "middle of the road" projection because it assumes that future climate will be impacted by a balance of both fossil fuel and non-fossil fuel energy sources. For the purposes of this study, A1B was determined to be appropriate for planning purposes.

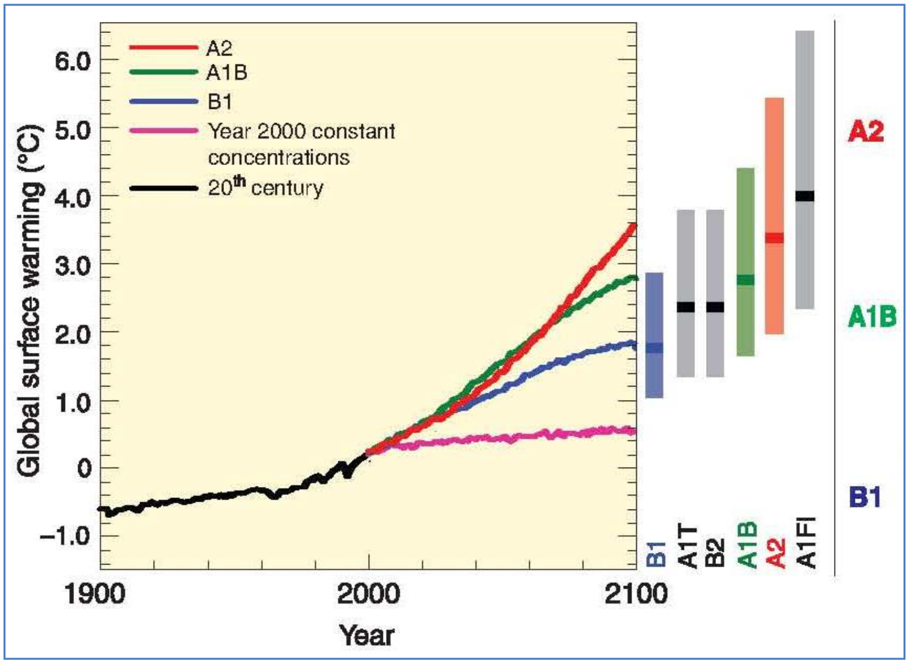

Figure 8. IPCC Emissions Scenarios[10]

CREAT provided three pre-loaded scenarios for the two study locations, based on GCM results, which capture a range of possible future climate conditions: 1) hot and dry, 2) central, and 3) warm and wet model projections. The hot and dry, central, and warm and wet model projections each vary the change in precipitation and temperature differently. Data for these pre-loaded scenarios were available for the 2035 and 2060 time periods only. In both cases, the data were derived as 30-year averages, centered on the time period year. This means that the 2035 future precipitation values used in this study are a 30-year average from 2020 to 2050. Projected conditions were calculated as a change from an existing condition using the historical climate data set previously selected for each location.

For this study, the “warm and wet” model projection was used to extract future precipitation data for each community. The warm and wet model projection was chosen because it predicts the largest change in increased precipitation, which allowed the project team to assess a worst-case future flooding scenario for each community.

CREAT precipitation outputs are provided in inches for the 5-, 10-, 15-, 30-, 50- and 100-year, 24-hour storm events. The hydrology modeling described in Section 2.3.2 used a USGS regression equation that has a required input of the rainfall in inches for a TP-40 2-year, 2-hour precipitation event. Because CREAT precipitation outputs are for a 24-hour storm event only, the project team estimated the 2-year, 2-hour future predicted rainfall based on extrapolated data from CREAT. The future 2-year, 2-hour rainfall was estimated using the following steps:

The 5-, 10-, 15-, 30-, 50-, and 100-year storms referenced here are often referred to as “frequency storms” or “return interval” storms. They can be more accurately described as having an annual occurrence probability of 1/n where n is the numeral in the year storm in question. The 10-year storm, for example, would have an annual probability of occurrence of:

1/10 = 0.1

1. Obtain the CREAT-estimated percent change in precipitation between historic precipitation and 2035 precipitation (5-, 10-, 15-, 30-, 50- and 100-year, 24-hour storm events).
2. Use a logarithmic regression equation to extrapolate the percent change for the 2035 2-year, 24-hour storm based on the CREAT outputs in Step 1.
3. Estimate the TP-40 2035 2-year, 24-hour precipitation by increasing the TP-40 2-year, 24-hour precipitation by the percent change calculated in Step 2.
4. Determine the ratio between the TP-40 2-year, 2-hour precipitation and TP-40 2-year, 24-hour precipitation.
5. Estimate the 2035 2-year, 2-hour precipitation by adjusting the 2035 2-year, 24-hour precipitation (calculated in Step 3) by the ratio calculated in Step 4.

Further information on CREAT can be accessed at:
http://water.epa.gov/infrastructure/watersecurity/climate/creat.cfm

2.3.2 H&H Model

H&H models work together to convey how water moves below the earth’s surface, on the earth’s surface, and through engineered conveyance mechanisms. Hydrology refers to the flow of water through and on natural terrain. Hydraulics refers to the flow of water through natural or engineered channels and structures. There is overlap between H&H, which is why H&H are often modeled in tandem. There are many different models that can be used to assess H&H (e.g., Hydrologic Engineering Center Hydrologic Modeling System [HEC-HMS], MIKE11, WinTR-55); the models used here consider rainfall patterns and geophysical attributes of the watershed to predict how rainfall events will behave with regard to overbank flooding from streams.

H&H Model: USGS Regional Regression Equations[33]

HEC-HMS was initially selected as the hydrologic model in Duluth for this study as an existing HEC-1 (predecessor to HEC-HMS) model was available from the local sponsor in the city. However, the HEC-1 model was not fully functional and could not be updated for incorporation into HEC-HMS. An existing hydrology model for Toledo was not made available to the study team. Due to time and data availability constrains, a HEC-HMS model could not be built from scratch for either community, so an alternative method to estimate stream flow was needed.

USGS regression equations are a widely accepted means of estimating peak stream flow values for ungaged watersheds. Because the regression equations specifically address ungaged watersheds, they offer an advantage over more sophisticated data and labor-intensive models (e.g., MIKE 11) that require "calibration" to observed flows. Due to their robust application, ease of use, minimal data requirements, and ability to fit within the scope, timeline, and budget of this project, USGS regression equations were selected as the hydrologic model.

"Return interval" storms (or "frequency storms") are common in hydrologic terminology. They are often referred to as the 2-, 5-, 10-, 50-, and 100-year (and so on) storm. They can be thought of as having an annual occurrence probability of 1/n where n is the numeral in the year storm in question. The 10-year storm, for example, would have an annual occurrence probability of:

1/10 = 0.1

The USGS regression equations for ungaged sites were developed using watershed and climatic characteristics at gaged watersheds throughout the United States. For this study, regional regression equations were used to calculate a rural peak discharge for a selected return period (i.e., storm event) and then a national urban regression equation was used to convert this to an urbanized peak discharge based on impervious areas.

Inputs for the regional regression equations included the drainage area (square miles), basin storage (percent), and main channel slope (feet/mile). Inputs for the nationwide urban regression equation included watershed drainage area (square miles), main channel slope (feet/mile), basin storage (percent), basin development factor, percent impervious area, the TP-40 2-year, 2-hour rainfall event (inches) (see Section 2.3.1), and the rural peak discharge calculated for the region (cubic feet per second [cfs]).

Solving the USGS regression equations provided peak discharges within the study streams for a range of recurrence intervals, climate conditions, and land use scenarios. These peak discharges were used as inputs for the HEC-RAS hydraulic model. Additional information about data inputs and outputs for the H&H modeling in this study is provided in Appendix H.

Hydraulic Model: HEC-RAS version 4.1

HEC-RAS, developed by the USACE, was chosen as the hydraulic model for this study because it is an industry standard in one-dimensional hydraulic modeling.[34] It has a robust modeling capability and is easy to use. One other model considered for use was HEC-2, the predecessor to HEC-RAS.

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[33] U.S. Geological Survey (USGS) Regional Regression Equations for Estimating Magnitude and Frequency of Floods for Ungaged Sites. 1993. Retrieved from http://pubs.usgs.gov/wri/1994/4002/report.pdf.

[34] For more information on this model, see http://www.hec.usace.army.mil/software/hec-ras/

HEC-2 suffers several shortcomings compared to HEC-RAS, such as limited output capability and lack of geospatial capabilities, which is why it was not chosen for this study.

HEC-RAS has the ability to perform steady and unsteady flow simulations, sediment transport computations, and water quality analysis. Steady flow computations are based on solution of the one-dimensional energy equation or the momentum equation where the water surface profile is rapidly varied. The model has a variety of outputs, including water surface profiles, rating curves, hydrographs, and inundation and floodplain mapping.

HEC-RAS was initially used to import existing HEC-2 models of the study area in Duluth, Minnesota, with the intent of using available data and models to support the study process. However, the HEC-2 data were of questionable quality and had little documentation to aid in model refinement. Existing HEC-RAS data was obtained for Toledo, but the decision was made to develop a new hydraulic model for the study areas in Toledo, Ohio, and Duluth, Minnesota, using more recent data available from the local community. The general procedure for model development was:

- Obtain elevation and other geospatial (GIS) data of the study area.
- Develop a model schematic using ArcGIS and HEC-GeoRAS.
- Import HEC-RAS model geometry from ArcGIS.
- Refine model geometry within HEC-RAS.
- Perform steady flow simulation using flow values from the USGS regression equations.
- Develop inundation polygons and depth grids for the modeled alternatives using ArcGIS and HEC-GeoRAS.

HEC-RAS was used to compute water surface profiles and associated inundation mapping for various scenarios (precipitation, land use) and flooding within the study area. The inundation maps indicate where flooding can occur and the depth of flooding in those areas. They provide a visual basis for comparing flood damage impacts under different scenarios and for different design storms. The H&H modeling results include flood depth grids for each scenario that take into account future precipitation and land use scenarios within the study watershed. The flood depth grids were used as input in Hazus to assess the resulting economic damages to buildings from these flood events.

2.3.3 Hazus

Hazus is FEMA's nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes. Hazus uses GIS technology for potential loss estimates such as:

- Physical damage to residential and commercial buildings, schools, critical facilities, and infrastructure.
- Economic loss, including lost jobs, business interruptions, repair, and reconstruction costs.
- Social impacts, including estimates of shelter requirements, displaced households, and population exposed to scenario floods, earthquakes, and hurricanes.

Only physical damage to buildings was estimated for this study. Hazus produces loss estimates for vulnerability assessments and plans for flood risk mitigation, emergency preparedness, and response and recovery. The methodology deals with nearly all aspects of the built environment and a wide range of losses. The user can evaluate losses from a single flood event or for a range of flood events, allowing for annualized estimates of damages.

Hazus can operate at three levels, depending on the needs and expertise of the user, availability of data, and scale or area of analysis (i.e., regional vs. neighborhood) (see Figure 9). A Level 1 analysis uses default data and models that are included with Hazus software and draws from national databases at the census block level. Using these extensive national databases, users can make general loss estimates for a regional scale analysis (i.e., city or county scale). These databases contain information such as demographic aspects of the population in a study region, square footage for different occupancies of buildings, critical facilities such as hospitals and schools, and numbers and locations of bridges. The data come from the U.S. Census Bureau, and for nonresidential structures, from Dun & Bradstreet.

Hazus methodology and software are flexible enough so that locally developed inventories and other data that more accurately reflect the local environment can be substituted, resulting in improved loss estimates. A Level 2 analysis integrates locally relevant, user-supplied data for property or structure loss such as building footprint locations or parcel centroids, which can serve as a proxy for building locations. For identifying floodplains or flood inundation, user-supplied data can include flood depth data from engineering-based software such as HEC-RAS. A Level 2 analysis was conducted for this study and is further described below.

A Level 3 analysis requires even more sophistication, such as importing results from third-party studies and modifying assumed relationships for inputs such as depth-damage curves. Importing additional information is time-consuming, but making modifications that are site-specific can greatly improve damage estimation.

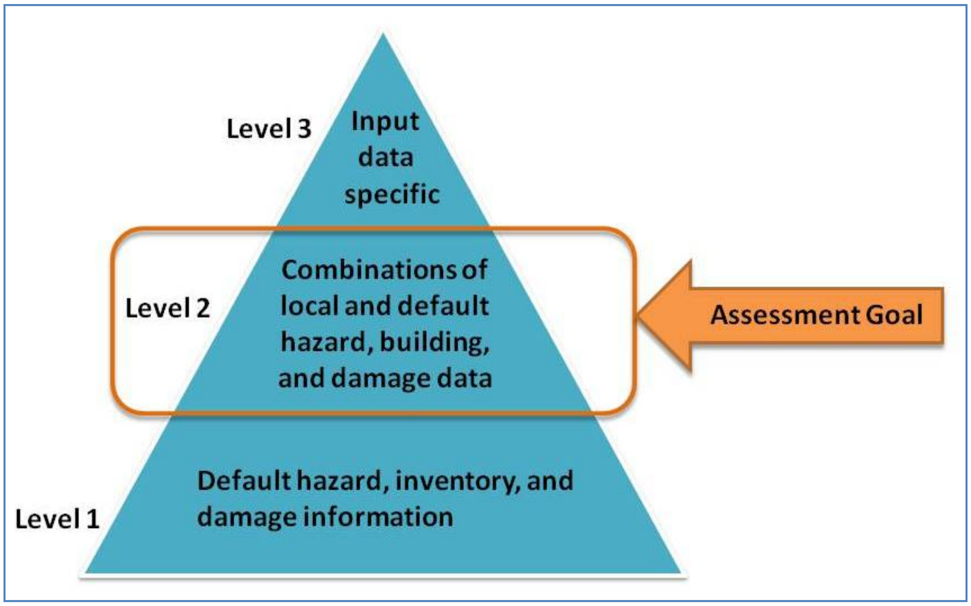

Figure 9. Hazus Level Analyses

Why Hazus Was Used for This Study

Hazus graphically illustrates the limits of identified high-risk locations due to flooding. In this study, it enabled visualization of the spatial relationships between populations located in flood-prone areas and how the shape and size of the flood-prone areas would change depending on the scenarios examined in this study. In addition to the visualization tool, outputs can be displayed as tables of social and economic losses. Most outputs can also be mapped or exported in various GIS data formats.

Hazus estimates the economic cost of flood damages for a community based on the assessed value of buildings and the estimated depth of flooding within each building or structure. Hazus can model the economic cost of flooding for various flood scenarios based on several variables (e.g., current and future climate, current and future land use). The resulting cost estimates associated with different flooding scenarios directly support the needs of this study in assessing the potential economic impacts of implementing GI and land use alternatives under various climate and land use scenarios.

Another reason that Hazus was chosen as the economic assessment tool for this study is because FEMA accepts Hazus loss estimation results for use in community hazard mitigation planning, which is required for any community that seeks post-flood disaster funding. Finally, one of the most important reasons that Hazus was chosen for this study is because of its standardized methodology for loss estimation and its ability to use nationally available datasets, allowing users to input their own more detailed information such as building footprint locations. Thus, this is an easily transferable tool that other communities can use and modify for their own purposes.

How Hazus Was Used for This Study

FEMA's Hazus 2.0, Service Pack 2 (Release 11.0.2) on Environmental Systems Research Institute (ESRI) ArcGIS 10.0 with Service Pack 2 (Build 3200) was used for all flood damage estimates in this study. Although Hazus can be used to estimate several types of flood damages noted above in Section 2.2.3, ***it was used in this study to estimate the physical building damage associated with selected flood model scenarios only.*** It is important to remember that the physical building damage estimated by Hazus is only one component of all economic or structural damages likely to occur from flooding.

A Level 2 Hazus analysis was completed for both communities in this project by importing parcel-level data and attributes and flood depth grids generated by the HEC-RAS models to show the relationship between building locations and flood areas. The basic steps for this study's Hazus analysis were:

1. Identify and acquire parcel and/or building data and assessment attributes.[35]
2. Format building datasets and attributes.
3. Import HEC-RAS flood depth grids (raster datasets) – a.k.a. "user-defined depth grids".
4. Delineate inundated areas.
5. Import building data into Hazus as User-defined Facilities (UDFs).
6. Run UDF analysis for each scenario that varied precipitation, land use, and the implementation of GI.

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[35] Most communities maintain tax or property assessment data linked to parcels by unique identifiers. Key attributes required include occupancy type (e.g., residential, commercial, retail); building value (e.g., assessed, market, replacement), square footage, foundation type, and more. For a full description of modeling process and required attributes see Appendix G - Hazus Methodology and Data Sources.

7. Export UDF results for each scenario and return interval.

Both communities had parcel-level data linked with the community's tax assessor database. Hazus requires a single point location for each building that will be analyzed. Building footprints are the ideal source for capturing the correct number of buildings and the most accurate location; however building footprints were not available from either community. Therefore the center point of the parcel (parcel centroid) was used to approximate where a building was located on the parcel, thus serving as a building proxy. When using the parcel centroid, it is assumed that there is only one building per parcel; it is recognized that some parcels will have multiple buildings and others parcels will be vacant and additionally that the building will not always be located at the parcel center. Some of these assumptions have been corrected and are described further in the Appendix G (Hazus Methodology and Data Sources). Overall, the parcel centroid produces a reasonable building proxy for both, location within the parcel, and number of buildings on the parcel since residential buildings are the predominant building type for both communities (typical residential parcels only have one house per parcel generally located near the parcel center).

It should be noted that Hazus-estimated damages below are likely to be lower than the damages that either community currently experience. Hazus estimates damages based on flood depth grids associated with modeled riverine flood inundation and does not account for water in the basement as a result of stormwater backup, flash flooding or antecedent conditions (saturated ground).

2.4 Evaluating Benefits

Benefits are represented as the amount of reduced damages because of flood reduction strategies. In other words, the dollar value of avoided costs is the benefit. First the economic impact of flooding is estimated under future land use and precipitation scenarios without implementing flood reduction strategies. Then, flood damages are estimated after implementing GI. The difference between these two estimates—the amount of reduced damages associated with flood reduction strategies—is represented as "benefits."

Benefits tend to be measured in disparate units; in order to 1) aggregate benefits, and 2) compare benefits to costs, the value of benefits must be monetized. However, not all benefits are easily quantifiable. For example, associating a monetary value with an improved wildlife habitat, increased green space, or an improved viewshed may require a contingent valuation study to be conducted. There are many "non-monetized" benefits associated with GI practices and policies. The true PV of implementing GI is much greater than is calculated from monetized benefits in this study.

The project team engaged community partners to identify the types of benefits that might be relatively easily estimated and achieved with their flood-reduction strategies. Monetized benefits are discussed here while other benefits are discussed in Appendix D. These potential additional benefits include improved water quality, increased habitat, improved aesthetics, and higher property values.

The following benefits were monetized in this report (in Toledo, only benefits from Hazus are assessed):

1. Reduced building damages
2. Increased recreational use
3. Reduced land restoration costs
4. Reduced storm sewer infrastructure costs

Annual benefits were assessed and the PV of these benefits estimated for a 20-year period. Determining the PV of benefits over multiple years takes into account that benefits may occur across different time horizons, based on the policies utilized. For example, some policies may have immediate returns that are fairly constant over time, whereas other policies may take years to yield returns, but once they do, they generate large benefits. To discount future benefits to reflect current dollars, a discount rate of 0.8 percent was used based on the discount rates from Office of Management and Budget (OMB) Circular No. A-94.[36] Future benefits must be discounted to reflect society's preference for immediate benefits over future benefits.

To evaluate the PV of benefits over 20 years, environmental and economic conditions must be forecast. For example, if precipitation is expected to increase over time, the benefits of flood mitigation may be larger in the future. The costs of flooding were determined for four scenarios:

1. Current land use and current precipitation (2013)
2. Future land use and future precipitation (2035)
3. Current land use and current precipitation with GI (2013)
4. Future land use and future precipitation with GI (2035)

Benefits in year 1 were measured as the difference between the baseline scenario (scenario 1) and the alternative scenario with GI (scenario 3). Benefits in year 23 (2035 minus 2013) were measured as the difference between scenario 2 and scenario 4. Benefits for years 2 through 22 were estimated using linear interpolation. The PV was estimated by aggregating the discounted annual expected benefits from year 1 through year 20. Although the PV reported is for 20 years, benefits for 23 years must be estimated since the future scenarios considered are for 2035 (23 years after the base year). Therefore, the PV could be reported for 23 years but a 20-year time horizon is more commonly used and may be more appropriate for planning purposes.

Benefits of GI are not necessarily achieved immediately; time must be allocated for designing and constructing the GI, and benefits only accrue after the GI is in place and functioning. Therefore, the 20-year PV depends on the type of GI selected and time needed for implementation. Since we did not know what type(s) of infrastructure the communities will implement, nor in what sequence and over what period of time implementation would occur, we had to make some assumptions. We assumed that it takes two years for the GI to be fully implemented; therefore, in years 1 and 2 of the analysis, the benefit of GI was estimated to be zero (i.e., scenario 1 equals scenario 3). If the time lag is longer, then the PV would decrease; conversely, if the time lag is shorter, then the PV would increase.

The actual costs of flooding, and the resulting benefits of flood reduction strategies, depend on the severity of storms that occur. Therefore, when assessing expected benefits, the probabilities of storms of various severities occurring are used. Since the severity of storms is a continuum, benefits are assessed using expected annual damage (EAD) computations. EAD computations are widely used in the field to account for the continuous nature of both storm severities and probabilities of

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[36] 0.8 percent is the predicted 2014 real interest rates on treasury notes and bonds with a 20-year maturity. Retrieved from: http://www.whitehouse.gov/sites/default/files/omb/memoranda/2013/m-13-04.pdf.

occurring. In essence, EAD calculations smooth benefits across discrete storm severities (e.g., 2-year, 5-year).[37]

Reduced Structural Damages

Hazus was used to estimate reduced building damages (see Section 2.3.3). The model estimates costs across a variety of storm sizes and the precipitation and land use scenarios defined above. To assess benefits, EAD with and without GI must be identified (see Figure 10). To start, EAD (with and without GI) were estimated for the first and last year of the analysis:

- **EAD1:** EAD in 2013 (year 1 of the analysis) without flood reduction are estimated using scenario 1 (current land use and current precipitation).
- **EAD2:** EAD in 2035 (year 23 of the analysis) without flood reduction are estimated using scenario 2 (future land use and future precipitation).[38]
- **EAD3:** EAD in 2013 with flood reduction are estimated using scenario 3 (current land use, current precipitation, and adaptive GI).
- **EAD4:** EAD in 2035 with flood reduction are estimated using scenario 4 (future land use, future precipitation, and adaptive GI).

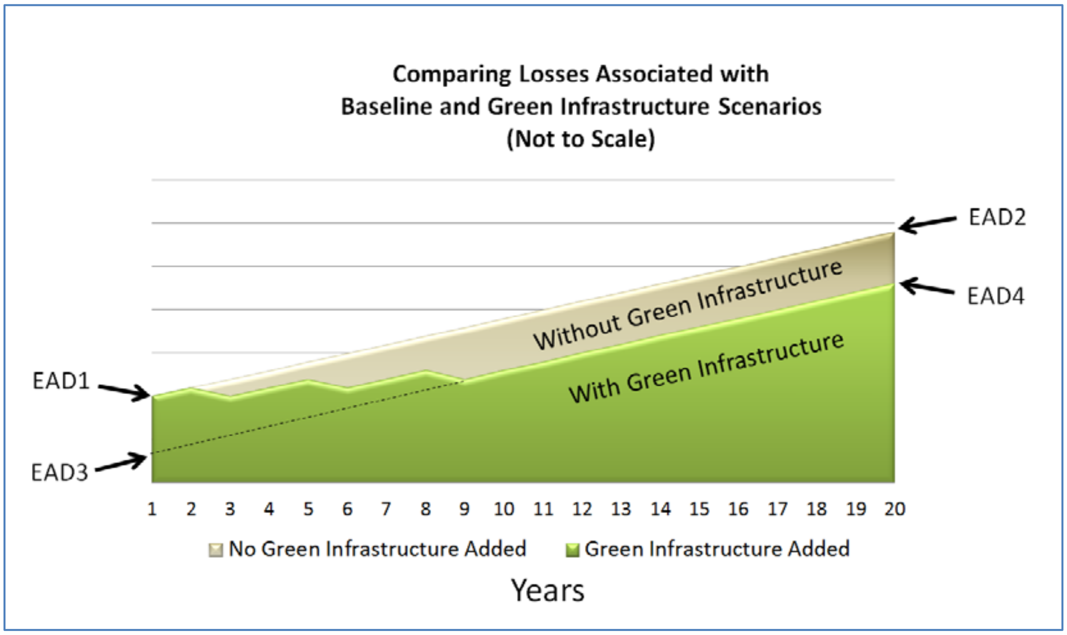

Figure 10. Expected Annual Damages With and Without Green Infrastructure

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[37] EAD calculations assume damages to be constant in the intervals between return periods (e.g., 2-year, five-year) and equal to the average of damages at each end point. So for the return interval (two to five years), damages are assumed to be equal to the damages for the five-year flood plus the damages from the 2-year flood, divided by two. The probability of a flood occurring in this range is equal to the probability of the first endpoint (in this example, 1/2, or 0.5) minus the probability of the second endpoint (here, 1/5, or 0.2).

[38] Hazus output is for 2035; if 2013 is used as the first year then benefits are estimated for 23 years. Since we are estimating the PV over a 20-year period, the last three years of calculated benefits (2033 to 2035) are not included in the PV calculation.

EAD for years between 2013 and 2035 were interpolated using EAD values determined above. For example, the EAD without GI in years 2013 and 2035 have been estimated but the EAD in years 2014 through 2034 are unknown, although they must fall between these two values. Interpolation of these values is done by taking the total change over the 23-year period (EAD2 minus EAD1) and dividing by 22. This provides the average annual increase (denominated as x). Then the level of EAD in year 2 without GI is estimated as the level of damages in year 1 (EAD1) plus x.[39]

As discussed earlier in this section, the benefits of flood damage reduction are assumed to not take effect until year 3 of the analysis (to allow time for GI to be implemented); therefore, the benefits in years 1 and 2 are replaced with zero (opposed to the difference between damages with and without GI (e.g., EAD3 minus EAD1 for year 1). Once EADs were estimated for every year for these four scenarios, benefits can then be calculated as the difference between EADs with and without GI. The 20-year PV is then calculated by summing the discounted benefits for years 1 through 20.

2.4.1 Future Cost-Benefit Analysis

In this report the total costs associated with reduced flooding are not considered because the costs vary based on the timing and types of GI implemented. Quantifying the size and location of implemented GI practices for flood storage was not a component of this study and would be needed as a next step in refining total costs. However, cities could estimate the cubic feet of flood storage desired by different GI practices and then use the provided costs per cubic foot of runoff storage in this report (see Table 3 and Table 16) to estimate the GI costs associated with their implementation plans. The lowest total cost for GI implementation would occur if a community installed only the least expensive type of GI. The largest total cost for GI implementation would occur if a community installed only the most expensive type of GI. The most likely scenario, however, is that a community will install various types of GI practices at different cost points. Communities can utilize the costs in Table 16 to estimate what it would cost to implement combinations of GI practices to obtain a desired level of flood storage. In order to reduce marginal costs, communities should focus on less expensive green infrastructure solutions and sequencing GI implementation with other capital projects or funding sources. Additionally, communities must consider the lifespan of the GI project as an important factor in determining the timeframe over which to compare benefits and costs. It should be noted that although the total estimated cost for implementation may seem large, these costs are anticipated to be spread over long periods of time (e.g., 20 years) as communities gradually implement GI to increase flood storage.

To estimate the cost of GI, the community would multiply the unit cost of the type of GI times the volume of flood storage needed. For example, if 6 acre-feet of storage was provided by constructing extended detention wetlands at a unit cost of \$l.3 per cubic foot, it would cost: $\$1.3/\mathrm{ft}^{3}$ x 43,560 ft^{2}/acre x 6 acre-feet = roughly \$340,000

When comparing costs and benefits, it is critical to keep in mind that not all costs and benefits can be monetized (this is especially pertinent for benefits). Monetizing costs is relatively straightforward, as these are essentially commercial transactions (although determining the appropriate market price for some potential policies, such as those placing restrictions on land use, might be complex). However, many benefits cannot be easily monetized (as is the case here).

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[39] Specific numbers are not used in this example to keep it applicable to both communities. See Appendix D for EADs and PV estimates.

Consequently, even if costs are estimated and a cost-benefit analysis is conducted, this may not provide a clear determination regarding whether the project is economically effective. If some benefits are not monetized, then the project may be worthwhile even if the costs are higher than the limited set of benefits that are monetized. Under this scenario, one must assess the non-monetized benefits and use qualitative reasoning to decide whether total costs outweigh total benefits and hence whether the project should be implemented.

Table 3. Hypothetical GI Cost Calculation Table

Green Infrastructure Practice	Capital Cost per Cubic Foot ($/CF)	Potential Storage Volume (CF)	Estimated Cost ($)
Bioretention	21.2	500,000	10,600,000
Blue Roof	6.0	150,000	900,000
Permeable Pavement	16.8	50,000	840,000
Retention Pond	2.9	500,000	1,450,000
Extended Detention Wetland	1.3	1,000,000	1,300,000
TOTAL		2,200,000 CF (50.5 acre-feet)	$15,090,000

3.0 TOLEDO, OHIO

The Silver Creek watershed was chosen for the assessment in Toledo, Ohio. Community background information and a summary of results from the modeling scenarios and economic assessment are presented below.

3.1 General Statistics and Land Use Background

The city of Toledo, Ohio, is located in northwestern Ohio, near the shore of Lake Erie (see Figure 11). It has a humid continental climate[40] and a mostly flat topography that drains to Lake Erie. The county occupies approximately 596 square miles[40] and Toledo consists of approximately 80.6 square miles within the county.[41] The Maumee River is a major environmental asset in Toledo, attracting redevelopment and activating the waterfront in downtown Toledo. Silver Creek flows into the Maumee River, which, in turn, flows into Lake Erie.

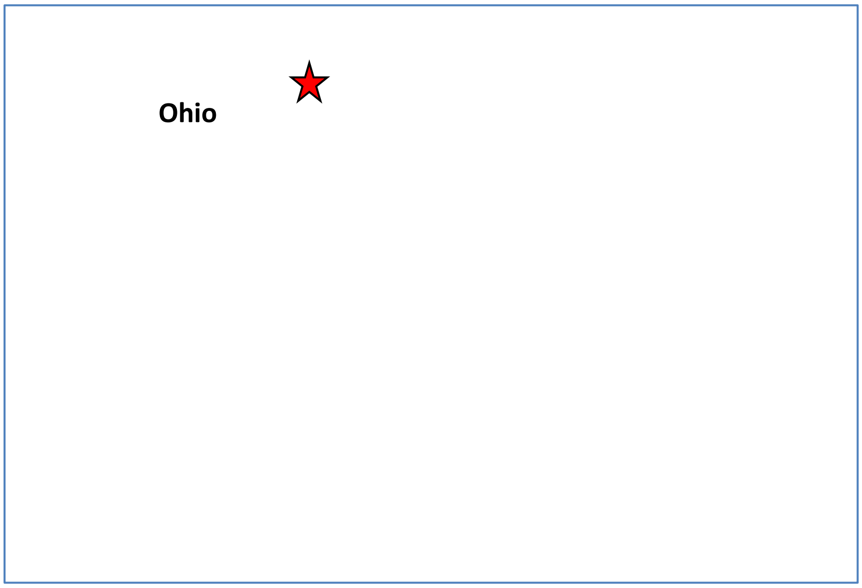

Figure 11. State of Ohio Map

In 2012, Toledo's population was 284,012.[41] It is important to note that Toledo is nearly fully developed and therefore future development will not likely have a significant increase on flooding. However, Toledo faces important decisions about whether to rebuild or buy out properties in flood-prone areas and whether to shift development density away from floodplains to promote sustainable development and reduce flood damages in the future. In addition, redevelopment outside flood-prone areas may present opportunities to reduce flooding by retrofitting GI and increasing storage.

Toledo is actively working to recover from a recent economic downturn and demographic decline. Toledo's estimated median household income was $31,090 in 2011, down slightly from $32,436 in 2000. The estimated median house or condominium value was $81,900 in 2011, up from $73,700 in

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[40] Federal Emergency Management Agency. (2011). Flood Insurance Study: Lucas County Ohio and Incorporated Areas.
[41] U.S. Census Bureau. State and County Quick Facts: Toledo, Ohio. Retrieved from http://quickfacts.census.gov/qfd/states/39/3977000.html.

2000.[42] The economic downturn resulted in numerous foreclosures and housing vacancies within the city; while this is certainly an economic challenge, it can also be viewed as an opportunity to make informed decisions about the future use of those parcels.

3.2 Watershed Selection and Characteristics

The project team discussed watershed selection during a community meeting in Toledo in January 2013. While in Toledo, the team toured various watersheds within the city where there were flooding issues and opportunities for GI. A final decision on the watershed to study was made during a community meeting via webcast in March 2013.

The main site selection criteria included:

- Significant flooding damages reported within the watershed.
- Opportunities for future land use with GI within the watershed.
- Available data for H&H modeling.

The community meeting participants chose Silver Creek as the watershed of interest for the study (see Figure 12). Silver Creek flows in an easterly direction at the north end of Lucas County close to the Ohio and Michigan state border. Silver Creek discharges into Lake Erie and has a total drainage area of 15.7655 square miles, which includes the drainage area of Shantee Creek that flows into Silver Creek. The drainage area of Silver Creek alone (i.e., the area upstream of where Shantee Creek joins Silver Creek) was assessed in this study and is 7.4156 square miles.

The USGS National Elevation Dataset (NED) was used to further delineate sub-watersheds within the Silver Creek watershed to obtain drainage areas and flow change locations for use in the USGS regression equations and HEC-RAS model. The NED for Silver Creek was processed using the standard suite of hydrology tools available in ArcGIS ArcHydro toolbox, resulting in a total of 16 sub-watersheds.[43] All peak discharges and velocities provided for Silver Creek are from River Station 8071 (see Figure 12). River Station 8071 was chosen as the best representative location to portray behavior of the Silver Creek watershed as a whole because it is the river station immediately upstream of the location where Shantee Creek discharges into Silver Creek. All river stations downstream of River Station 8071 would include peak discharge contributions from Shantee Creek and were not assessed.

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[42] Toledo, Ohio City Data. Retrieved from http://www.city-data.com/city/Toledo-Ohio.html.

[43] The sub-watershed were delineated using the National Hydrography Dataset 12 digit hydrologic unit code (HUC) for the watershed boundary. The sub-watersheds for the H&H modeling were created from the hydrologically processed NED and are the sub-watershed boundaries used in this study. The 12 digit HUCs do not always agree with site-specific watershed delineations, though most of the time they generally agree.

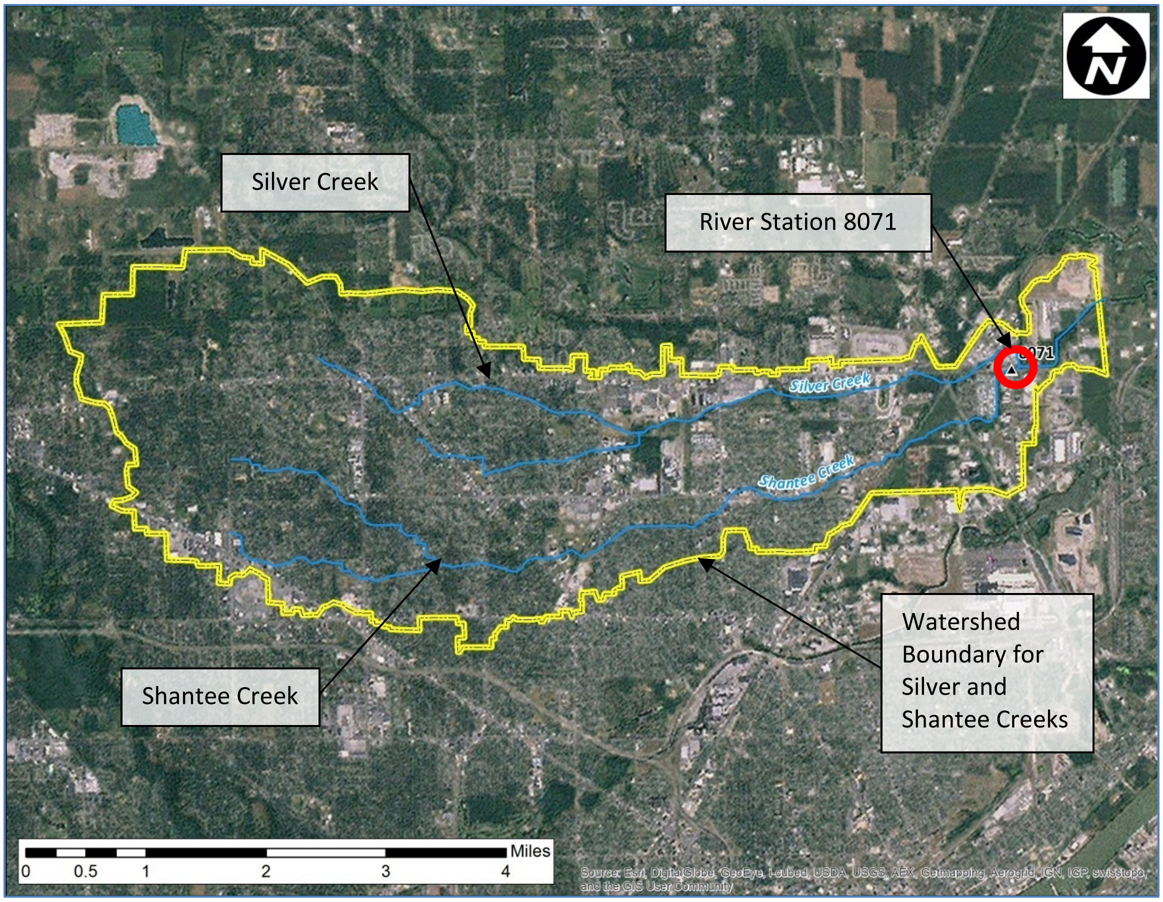


Figure 12. Silver Creek and Shantee Creek Watersheds

Land use within the Silver Creek watershed is primarily residential and commercial (see Figure 13). As is typical of the city, most of the watershed is developed and there are minimal areas with significant open space. There are also opportunities, which Toledo has taken advantage of in the past, to buy out flood-prone properties to reduce repeat flood damages and restore flood storage functionality. There are also opportunities for retrofitting existing land uses as they are redeveloped to incorporate GI to provide flood storage.

A unique aspect of Toledo is the availability of numerous tax-forfeited parcels throughout the city. These vacant parcels present opportunities for the city to implement GI and provide flood storage. Transforming these vacant parcels into GI would not only provide stormwater benefits, but, if strategically planned in connection with public amenities such as bikeways, walkways or pocket parks, could also improve neighborhood aesthetics, recreation, habitat, and nearby property values.

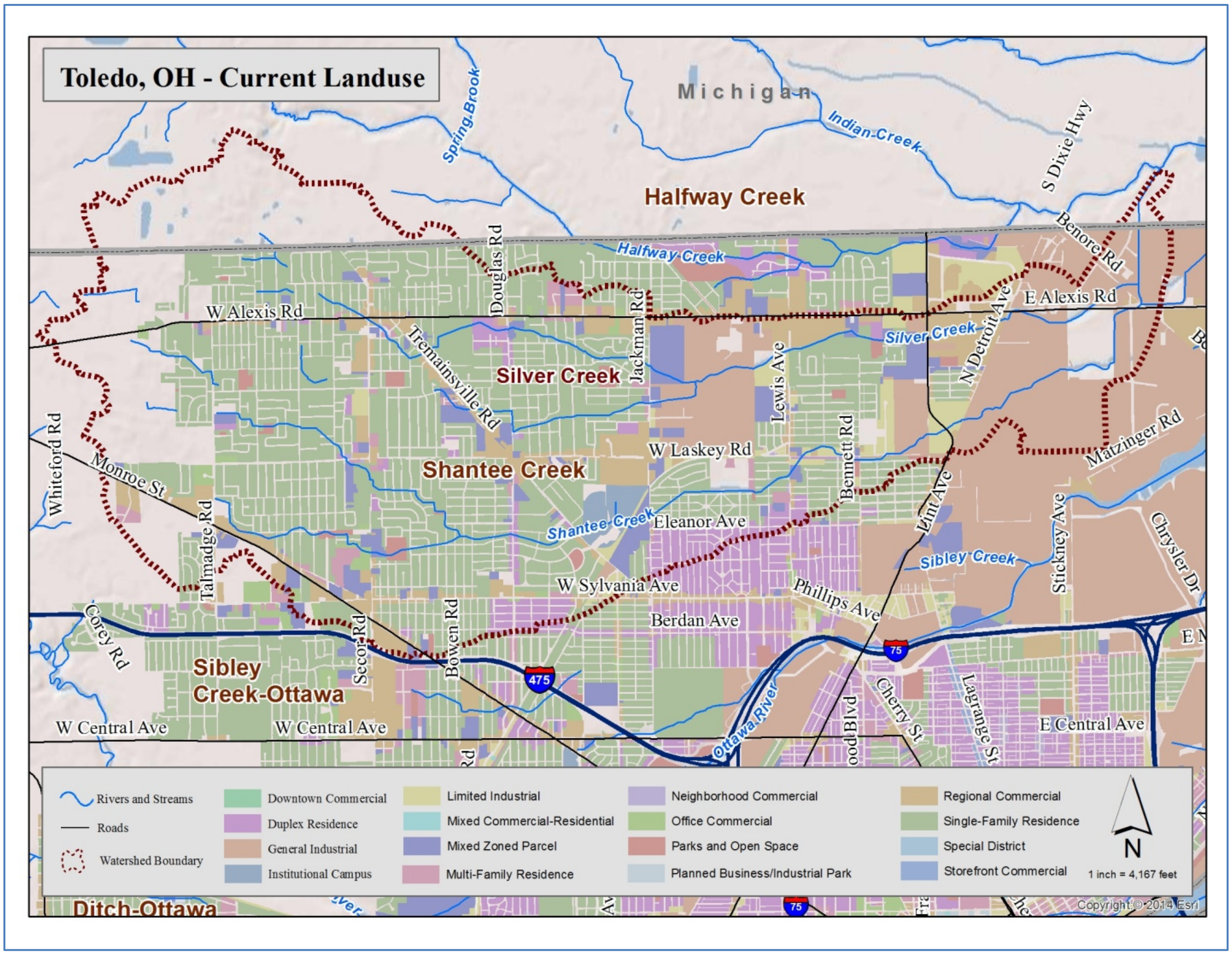


Figure 13. Toledo Current Land Use

The Silver Creek watershed in Toledo is heavily developed with flat topography. There are distinct areas most subject to flooding and other pockets of flooding and ponding scattered throughout the watershed. Residential and commercial properties, as well as infrastructure (e.g., roads, storm sewer pipes) are most affected by flooding events within Silver Creek. Toledo experiences negative impacts from flooding on a regular basis. Much of the existing flood plain has been developed, which contributes greatly to flooding damage because stormwater runoff has nowhere to infiltrate or be stored. The city of Toledo currently receives numerous complaints about basement and street flooding during both small and large storm events (see Figure 14, which maps 97 percent of calls received between 2007 and 2012 according to the city of Toledo). These complaints will likely increase in future precipitation scenarios that are predicted to have increased precipitation amounts (intensity) and increased storm occurrence (frequency).

Figure 14. Toledo Complaints Summary (2007 through 2012) for Calls Received Regarding Water in Basement and Standing Water in Street

Because the Silver Creek watershed is nearly fully developed, the majority of flood mitigation strategies will need to be implemented as retrofits on already developed land. Opportunities for large storage areas are limited. Additionally, existing development within the floodplain will be difficult to reduce without considering options such as buy-outs where the city could partner with FEMA to purchase properties within the flood plain to restore its predevelopment hydrologic function.

3.3 Climate Modeling

CREAT was used to determine average annual current (2013) and future (2035) precipitation values for this study. Historic climate data from CREAT were used to represent the current precipitation inputs in this study. The historical average annual precipitation for Toledo is 34.2 inches. Current precipitation data used by CREAT for this project were from the Toledo Express WSO AP Climate Station (see Figure 15).

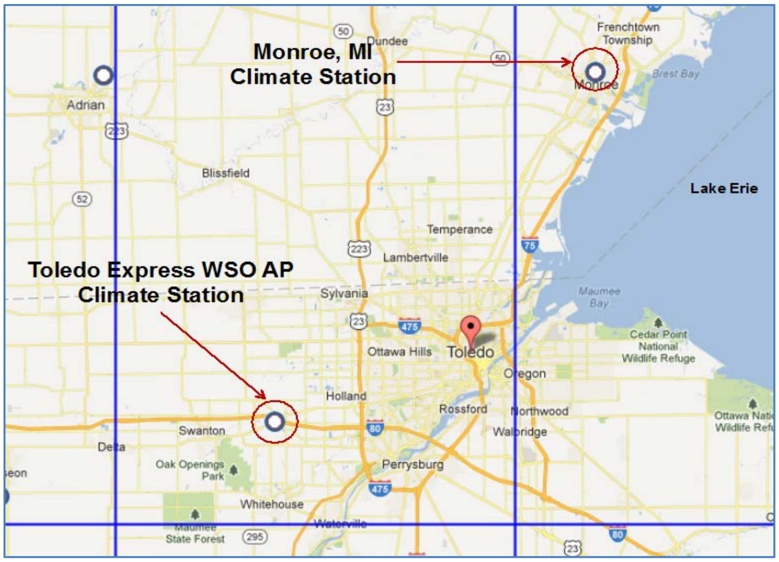


Figure 15. Toledo CREAT Climate Station

A variety of factors influence local precipitation patterns, but many climate science experts agree that in the future a significant amount of annual precipitation will likely come from intense or extreme rainfall events. According to CREAT outputs, projected changes in average annual precipitation vary widely from a 3.2 percent decrease to an 8.9 percent increase in Toledo (see Table 4). The projections in Table 4 are the range of values from the three CREAT model projections (hot and dry, central, and warm and wet). The warm/wet model projection was the climate scenario used to extrapolate precipitation data for Toledo in this study because it provides a worst case scenario with the greatest increase in precipitation throughout the year.

Table 4. Toledo Climate Data Projections

Future Time Period	Climate Scenarios[a]	Percent Change in Average Annual Precipitation
2020 - 2050	Hot and Dry	-3.2%
	Central	2.88%
	Warm and Wet	4.85%
2045 - 2075	Hot and Dry	-5.85%
	Central	5.27%
	Warm and Wet	8.87%

Source: Data extracted from EPA's CREAT.

Table Note a: For a detailed description of the methodology used to develop the future climate scenarios, please see the Methodology Guide within EPA's CREAT software.

Climate projections extracted from CREAT for Toledo mirror the regional findings in the scientific literature, illustrating an increase in intense precipitation events for the time periods of 2020 to 2050 and 2045 to 2075. Projections for Toledo show an increase in the frequency of the 100-year storm event (see Table 5). The 100-year storm event is used to describe a precipitation event that has a one percent probability of occurrence in any given year. The Toledo projections indicate a more significant increase in the 100-year storm event during the second half of the 21st century (2045 to 2075) than in the first half of the 21st century (2020 to 2050). The frequency of intense rain events, both 24-hour and multiday, will almost certainly continue to increase during the 21st century, which will subsequently increase the risk of flooding throughout Toledo's watersheds.[11]

Table 5. Toledo Projected Change in the Frequency of the 100-Year, 24-Hour Storm Event

Climate Scenarios[a]	Time Period 2020-2050	Time Period 2045-2075
Hot and Dry	5.78%	10.57%
Central	1.18%	2.15%
Warm and Wet	0.58%	1.07%

Table Note a: For a detailed description of the methodology used to develop the future climate scenarios, please see the Methodology Guide within EPA's CREAT software.

It should be noted that the percent change in annual precipitation does not necessarily correlate with the same percent change in received intense rainfall events. For example, intense and extreme rainfall events could increase at the same time that overall annual precipitation decreases and vice versa. Alternatively, it is possible that as intense precipitation events increase, the average annual precipitation will also increase. According to the CREAT data for Toledo, under the warm and wet model, both average annual precipitation and the frequency of the 100-year, 24-hour storm event will increase.

The resultant flooding from increased precipitation in Toledo may negatively impact the city's built and natural infrastructure, local industries, businesses, and human health. Since Toledo currently experiences flooding from precipitation events that are less intense than the 100-year storm, the projected increase in heavy precipitation events will likely impose a large burden on the city to improve stormwater runoff management techniques.

Sections 3.4 through 3.7 discuss the modeling in this study used to assess four different scenarios:

1. Current precipitation and current land use.
2. Future precipitation and future land use.
3. Current precipitation and current land use with provided flood storage.
4. Future precipitation and future land use with provided flood storage.

As is indicated from the CREAT data summarized in this section, precipitation is likely to increase in the future. Flooding is an issue in Silver Creek under current conditions, which means that an increase in precipitation will exacerbate the problem. An increase in precipitation not only leads to increased flooding, but also means that the odds of receiving precipitation that causes flooding damage will increase. For example, assume that the storm at which flooding damage occurs in Silver Creek is a 2-year storm event (i.e., a storm with a 50 percent chance of occurring in any given year) with a peak discharge of 496 cfs at River Station 8071. This means that under current conditions there is a 50 percent chance that a storm with a peak discharge of 496 cfs, which causes damage, would occur. In 2035 under the assumed future conditions, a peak discharge of 496 cfs at River Station 8071 has 68.75 percent chance of occurring rather than 50 percent (see Table 6). This means that under future conditions there is a 68.75 percent chance that a storm with a peak discharge of 496 cfs, which causes damage, would occur. The chance of having a storm that causes damage increases by 37.5 percent for the Silver Creek watershed.

Table 6. Frequency Increase of Peak Discharges

Scenario		Percent Chance[a] 496 cfs (current 2-year) Peak Discharge	Percent Chance 702 cfs (current 5-year) Peak Discharge	Percent Chance 895 cfs (current 10-year) Peak Discharge	Percent Chance 998 cfs (current 25-year) Peak Discharge	Percent Chance 1,119 cfs (current 50-year) Peak Discharge	Percent Chance 1,255 cfs (current 100-year) Peak Discharge
1	Current land use/current precipitation	50.00%	20.00%	10.00%	4.00%	2.00%	1.00%
2	Future land use/future precipitation	68.75%	24.10%	9.03%[b]	5.34%	2.89%	1.45%
3	Current land use/current precipitation/flood storage[c]	44.44%	13.16%	4.21%	2.29%	1.12%	0.50%
4	Future land use/future precipitation/flood storage[c]	51.94%	16.21%	5.44%	3.04%	1.53%	0.71%

Source: Data calculated using USGS Regression Equation.

Table Notes:

a. The percent chance in any given year.

b. A logarithmic equation was fit to peak discharge data in order to calculate the percent chance of occurrence for various peak discharges. The logarithmic equation is not a perfect fit and the line does not align perfectly with the known data points. The percent chance of an 895 cfs peak discharge occurring is therefore underestimated because of the imperfect fit of the logarithmic line. It is estimated that under future land use and future precipitation conditions the chance of an 895 cfs peak discharge occurring is actually greater than ten percent.

c. Flood storage for Silver Creek is assumed to be 10 percent of flow from current conditions.

Ultimately, an increase in precipitation and impervious area leads to an increase in the frequency of damaging storm events occurring. Assessing how the frequency of damaging storm events will change under different precipitation and land use assumptions is a powerful tool that communities can use to help mitigate flooding and plan for the future. Table 6 shows that increasing flood storage under scenarios 3 and 4 reduces the frequency of receiving a peak discharge that causes damage.

3.4 Modeling Scenario 1: Current Land Use and Current Precipitation

3.4.1 H&H Results

A USGS regression equation was used for the hydrology modeling to calculate the peak discharge of the sub-watersheds within Silver Creek. Sub-watersheds for Silver Creek were delineated by processing USGS NED terrain data (1/9 arc-second GRID) with the standard set of hydrology tools available in ArcGIS Spatial Analyst Toolbox. Sixteen sub-watersheds were delineated, including one sub-watershed for the entire Shantee Creek watershed. Regional regression equations were used to calculate a rural peak discharge for a selected return period (i.e., storm event), and then a national urban regression equation was used to convert this to an urbanized peak discharge based on impervious areas. Impervious area for each sub-watershed was obtained by using the zonal statistics tool (ArcGIS) on the National Land Cover Dataset developed and maintained by the Multi-Resolution Characteristics Consortium (MRLC). Values for impervious area based on future development were obtained from the local sponsor. 2-year, 2-hour TP-40 precipitation values are required to be used in the USGS regression equation. For Toledo, the current 2-year, 2-hour TP-40 precipitation is 1.5 inches. The calculated Silver Creek peak discharges at River Station 8071 range from 496 cfs for a 2-year storm to 1,255 cfs for a 100-year storm under current precipitation conditions (see Table 7). Velocities associated with storm intervals were calculated using the HEC-RAS hydraulic model. Peak discharge velocities range from 2.14 feet per second (ft/s) for a 2-year storm to 3.23 ft/s for a 100-year storm.

Table 7. Silver Creek Current Land Use and Current Precipitation Peak Discharges and Velocities

Recurrence Interval	Peak Discharge (cfs)	Velocity (ft/s)
2-year	496	2.14
5-year	702	2.50
10-year	895	2.80
25-year	998	2.94
50-year	1,119	3.09
100-year	1,255	3.23

Source: Data calculated using USGS Regression Equation.

The peak discharges from the USGS regression equation were used as an input in HEC-RAS to determine flood depth grids from current storm events throughout the Silver Creek sub-watersheds.

3.4.2 Hazus Results

Hazus was used to estimate flood damages to buildings within the Silver Creek watershed based on the flood depth grids developed through H&H modeling. The Lucas County Auditor's Real Estate Information System (AREIS) was used to populate the required Hazus attributes needed for analysis (see Section 2.3.3).

Parcel centroids (the center point of a parcel) were assigned as proxies for all buildings within the Silver Creek watershed (see Figure 16). The parcel centroid was used to approximate where a building was located on the parcel, thus serving as a building proxy. When using the parcel centroid, it is assumed that there is only one building per parcel. The Silver Creek watershed lies in Ohio and Michigan. This study only assessed the parcel damage in Ohio from the data provided by the city of Toledo.

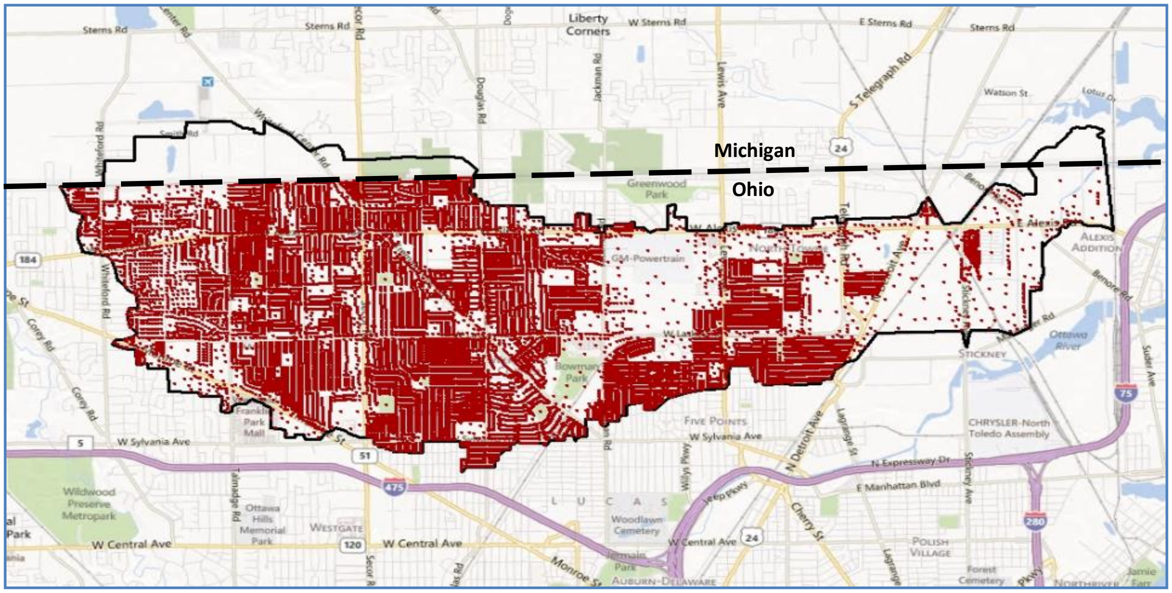


Figure 16. Silver Creek Parcel Centroids

The flooding damages for the current land use and current precipitation scenario in Silver Creek are summarized in Table 8. Again, it should be noted that Hazus-estimated damages below are likely to be lower than the damages the community currently experiences because only building damages were captured by this study's Hazus analysis (see Section 2.3.3).

Table 8. Silver Creek Current Land Use and Current Precipitation Flooding Damages

Recurrence Interval	Number of Buildings Damaged	Maximum Single Building Damage ($)	Total Damage ($)	Mean Damage Per Building ($)
2-year	20	$6,100	$53,400	$2,700
5-year	47	$8,900	$178,500	$3,800
10-year	68	$9,100	$248,100	$3,600
25-year	88	$44,200	$331,400	$3,800
50-year	149	$51,400	$464,000	$3,100
100-year	253	$52,000	$738,300	$2,900

Source: Hazus.

It was estimated that 68 buildings in Silver Creek were damaged, totaling $248,100 in costs, during the 10-year, 24-hour storm event under current precipitation conditions (see Figure 17). Flooding damages increased in Silver Creek as the storm recurrence interval increased. It was estimated that 253 structures in Silver Creek were damaged, totaling $738,000 in costs during the 100-year, 24-hour storm event under current precipitation conditions (see Figure 18). The neighborhood surrounded by the red box in Figure 18 has numerous damage points and is shown in more detail in Figure 19.

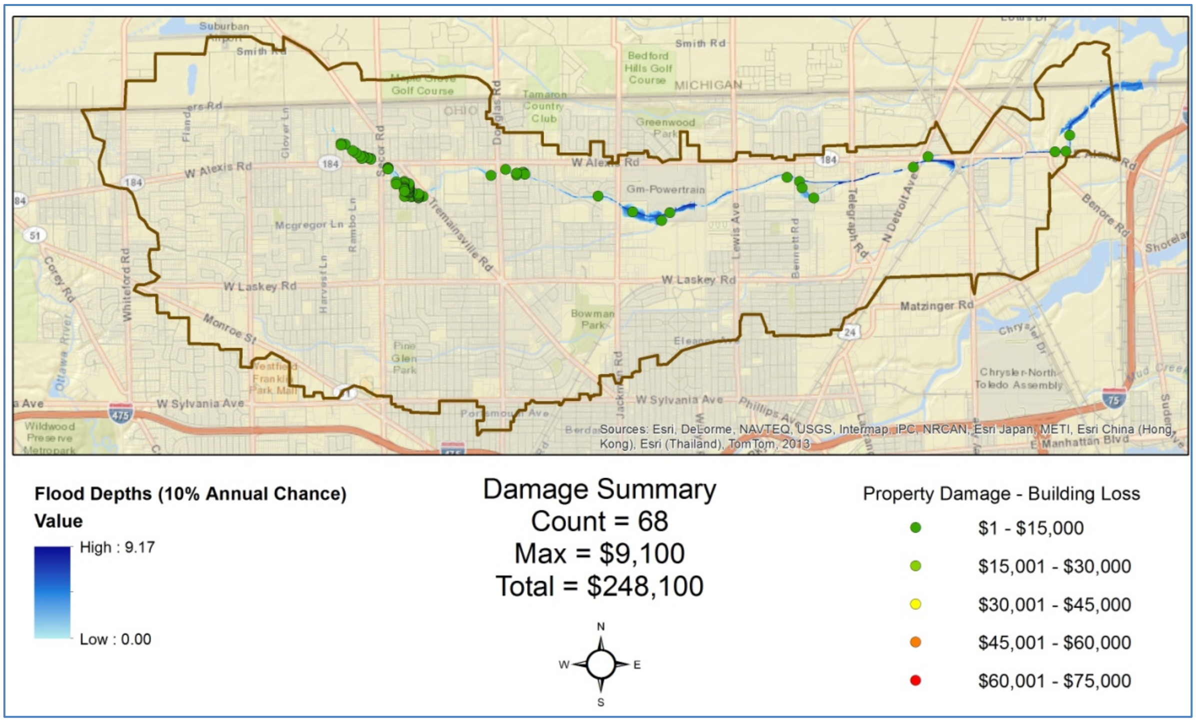

Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

Figure 17. Silver Creek Current Land Use and Current Precipitation 10-year, 24-hour Storm Flooding Damages

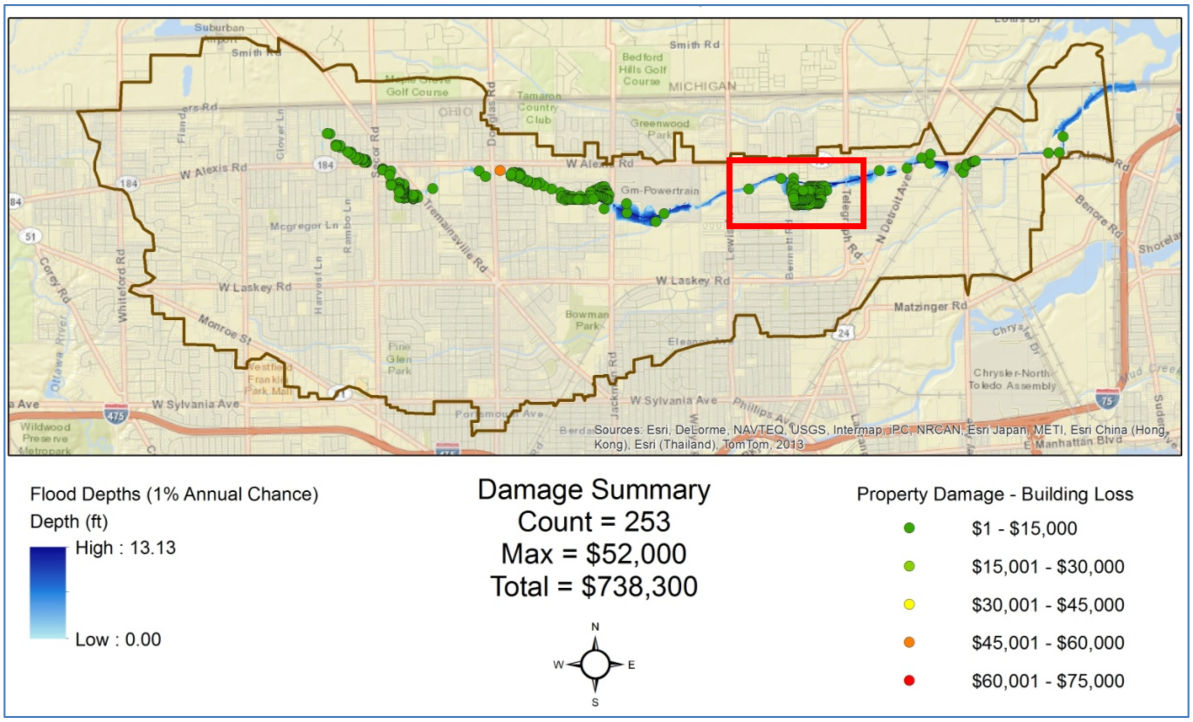

Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

Figure 18. Silver Creek Current Land Use and Current Precipitation 100-year, 24-hour Storm Flooding Damages

Flooding mitigation through the implementation of GI will be most economically beneficial if it is installed in upstream areas of the watershed that have clusters of damaged parcels. For example, Figure 19 shows a situation in which there is a clear cluster of parcels that will incur building damage according to Hazus. This would be a location in which stormwater runoff reduction and flood storage options should be focused.

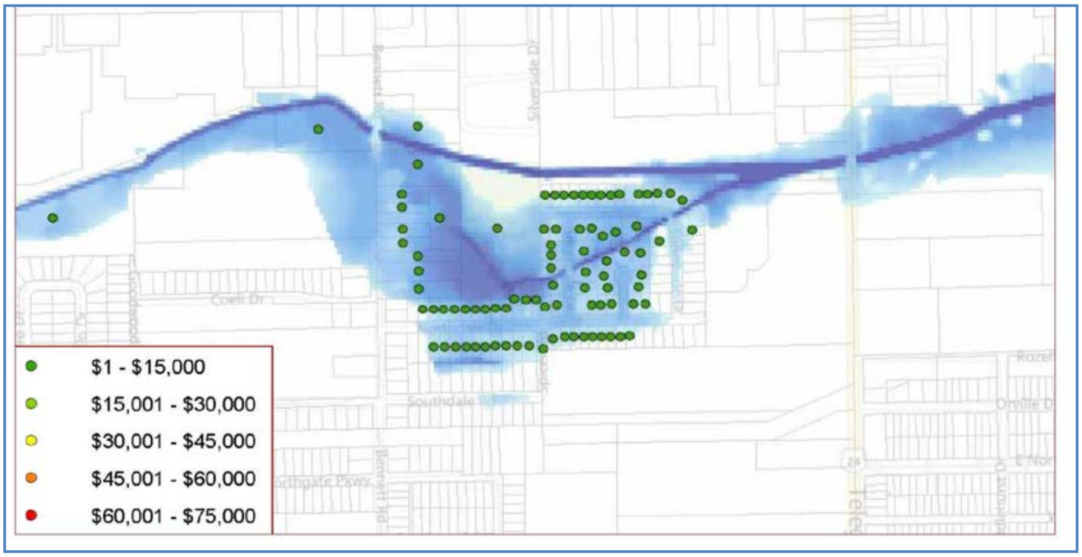


Figure 19. Silver Creek Current Land Use and Current Precipitation 100-year, 24-hour Storm Flooding Damages in One Neighborhood

3.5 Modeling Scenario 2: Future Land Use and Future Precipitation

The future year for this modeled scenario is assumed to be 2035. Future land use plans in the Silver Creek watershed include additional development, primarily in areas that were previously developed. This means that future development will not have a large impact on hydrology and increase the percent impervious area in a manner that would increase stormwater runoff. The primary cause of increased stormwater runoff would be increased precipitation rather than an increase in impervious area. Because of this, the future land use data (i.e., percent imperviousness and land cover) is assumed to be the same as the current land use data for this study. The future precipitation was estimated based on data extrapolated from CREAT.

3.5.1 H&H Results

A USGS regression equation was used for the hydrology modeling to calculate the peak discharge of the sub-watersheds within Silver Creek. Regional regression equations were used to calculate a rural peak discharge for a selected return period (i.e., storm event) and then a national urban regression equation was used to convert this to an urbanized peak discharge based on impervious areas. The future 2-year, 2-hour precipitation was estimated based on an extrapolation from CREAT. The extrapolation estimated that the 2-year, 2-hour TP-40 precipitation will increase by approximately 8.5 percent in the year 2035. For Toledo, the estimated future (2035) 2-year, 2-hour TP-40 precipitation is 1.63 inches, which is an 8.5 percent increase from the current 2-year, 2-hour precipitation value of 1.5 inches.

Overall, peak discharges increased five to six percent and velocities increased two to three percent compared to scenario 1. The calculated Silver Creek peak discharges for River Station 8071 range from 525 cfs for a 2-year storm to 1,378 cfs for a 100-year storm (see Table 9). Velocities associated with storm intervals were calculated using the HEC-RAS hydraulic model. Peak discharge velocities range from 2.20 ft/s for a 2-year storm to 3.31 ft/s for a 100-year storm. It should be noted that the relationship between peak discharge and velocity is not linear and will vary depending on factors such as river geometry and geology.

One limitation of 1-dimensional hydraulic models (like HEC-RAS) is that they provide AVERAGE velocities at a specific river station. Changes in flow may not result in a similar change in velocity as the relationship between the two is non-linear and highly dependent on site specific conditions. Velocity values presented here should be evaluated for relative changes and not as design values.

Table 9. Silver Creek Future Land Use and Future Precipitation Peak Discharges and Velocities

Recurrence Interval	Peak Discharge (cfs)	Velocity (ft/s)	Percent Change from Current Peak Discharge (Scenario 1)	Percent Change from Current Peak Velocity (Scenario 1)
2-year	525	2.20	6	3
5-year	739	2.57	5	3
10-year	940	2.87	5	3
25-year	1,048	3.01	5	2
50-year	1,174	3.16	5	2
100-year	1,318	3.31	5	2

Source: Data calculated using USGS regression equation.

The peak discharges from the USGS regression equation were used as an input in HEC-RAS to determine flood depth grids from future storm events throughout the Silver Creek sub-watersheds.

3.5.2 Hazus Results

Hazus was used to estimate future flood damages to structures within the Silver Creek watershed based on the flood depth grids developed through H&H modeling. Hazus assumptions in modeling scenario 1 (current land use and current precipitation) are the same for modeling scenario 2 (future land use and future precipitation). Damages in Silver Creek were greater for the future land use and future precipitation scenario than the current land use and current precipitation scenario. The increase in damages between Scenarios 1 and 2 are summarized in Table 10.

Table 10. Silver Creek Future Land Use and Future Precipitation Flooding Damages

Recurrence Interval	Number of Buildings Damaged	Maximum Single Building Damage ($)	Total Damage for all Buildings ($)	Mean Damage Per Building ($)	Total Damage Percent Change (from Scenario 1)
2-year	19	$8,500	$71,300	$3,800	25%
5-year	51	$9,000	$177,500	$3,500	-1%
10-year	74	$42,300	$274,600	$3,700	10%
25-year	104	$52,500	$358,100	$3,400	7%
50-year	167	$53,400	$518,300	$3,100	10%
100-year	293	$67,300	$980,800	$3,300	25%

Source: Hazus.

It was estimated that 293 structures in Silver Creek were damaged, totaling $980,800 in costs, during the 100-year, 24-hour storm event under future (2035) precipitation conditions (see Figure 20). When thinking about where flood storage would be most effective to handle predicted future precipitation, it helps to focus on the areas where there are clusters of damage in Hazus. The neighborhood surrounded by the red box in Figure 20 has numerous damage points and is shown in more detail in Figure 21. This is an example of an area in which flood storage options should be evaluated because of the concentration of predicted flood losses.

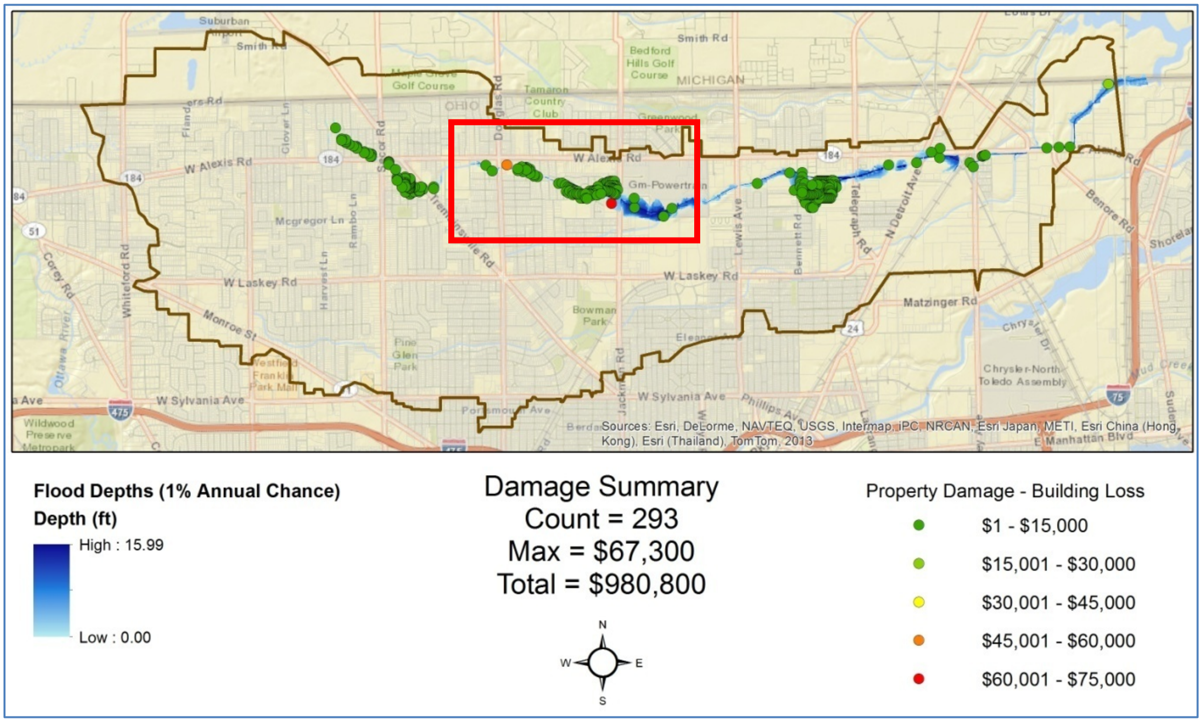


Figure 20. Silver Creek Future (2035) Precipitation 100-year, 24-hour Storm Flooding Damages


Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

Figure 21. Silver Creek Future (2035) Precipitation 100-year, 24-hour Storm Flooding Damages in a Neighborhood

3.6 Modeling Scenario 3: Current Land Use and Current Precipitation with Flood Storage

The goal of scenario 3 is to look at how the community could reduce flooding damage under current conditions in Silver Creek if a 10 percent increase in flood storage was provided. A 10 percent flood storage value was used because its associated 31 acre-feet value was assessed as an achievable goal within the Silver Creek watershed based on discussions with the community and their GI options of interest. In Scenario 3, all of the land use and precipitation assumptions are the same as in scenario 1. The difference in this scenario is that it is assumed that peak discharges are reduced by 10 percent at River Station 8071 through the implementation of stormwater management and GI upstream. A 10 percent reduction in peak discharge correlates to an associated storage volume of runoff. This scenario looks at the flooding damage caused if the current conditions in Silver Creek remain the same, except for a 10 percent increase in flood storage.

3.6.1 H&H Results

The 100-year, 24-hour peak discharge at River Station 8071 in Silver Creek is 1,255 cfs under scenario 1. That flow was reduced by 10 percent to 1,130 cfs for the scenario 3 analysis. Reducing peak discharges by 10 percent results in a four-to-five percent decrease in velocity for all storm events (see Table 11). A 10 percent peak discharge reduction for scenario 3 is equal to 31 acre-feet of flood storage. This means that if a community wanted to reduce peak discharges by 10 percent during a 100-year, 24-hour storm event, 31 acre-feet of storage would need to be provided upstream of River Station 8071.

Flood Storage Volume = (1,255 ft^3/sec - 1,130 ft^3/sec)(3 hours)(60 sec/min)(60 min/hr)(acre/43,560 ft^2) = 31 acre-feet. It was assumed that the peak flow is reduced by 10 percent for three hours. The three-hour reduction time was chosen based on engineering judgment and is somewhat arbitrary; however, it does provide an order of magnitude estimate of the storage volume needed for peak flow reduction.

Table 11. Silver Creek Peak Discharges and Velocities for Current Land Use and Current Precipitation with Flood Storage

Recurrence Interval	Peak Discharge (cfs)	Velocity (ft/s)	Percent Change from Current Peak Discharge (Scenario 1)	Percent Change from Current Velocity (Scenario 1)
2-year	446	2.05	-10%	-4%
5-year	632	2.38	-10%	-5%
10-year	806	2.67	-10%	-5%
25-year	898	2.81	-10%	-4%
50-year	1,007	2.95	-10%	-5%
100-year	1,130	3.10	-10%	-4%

Source: Data calculated using USGS regression equation.

Reducing peak discharges and accounting for 31 acre-feet of storage changes the flood depth grids generated by HEC-RAS. HEC-RAS was re-run assuming that 31 acre-feet of storage was added, which resulted in flood depth grids for the Silver Creek sub-watersheds that represent flooding when storage is provided under current land use and precipitation conditions.

3.6.2 Hazus Results

Hazus was used to estimate flood damages to buildings within the Silver Creek watershed based on the flood depth grids developed through H&H modeling of the current land use and current precipitation scenario with a 10 percent reduction in peak discharge flows (i.e., 31 acre-feet of storage). Hazus assumptions in scenario 1 are the same for scenario 3.

Reducing the peak discharge with the implementation of GI reduces the flood losses. It was estimated that 55 structures in Silver Creek were damaged, totaling $168,700 in costs, during the 10-year, 24-hour storm event under current precipitation conditions with the implementation of GI (see Figure 22). It was estimated that 159 buildings in Silver Creek were damaged, totaling $453,700 in costs during the 100-year, 24-hour storm event under current precipitation conditions (see Figure 23).

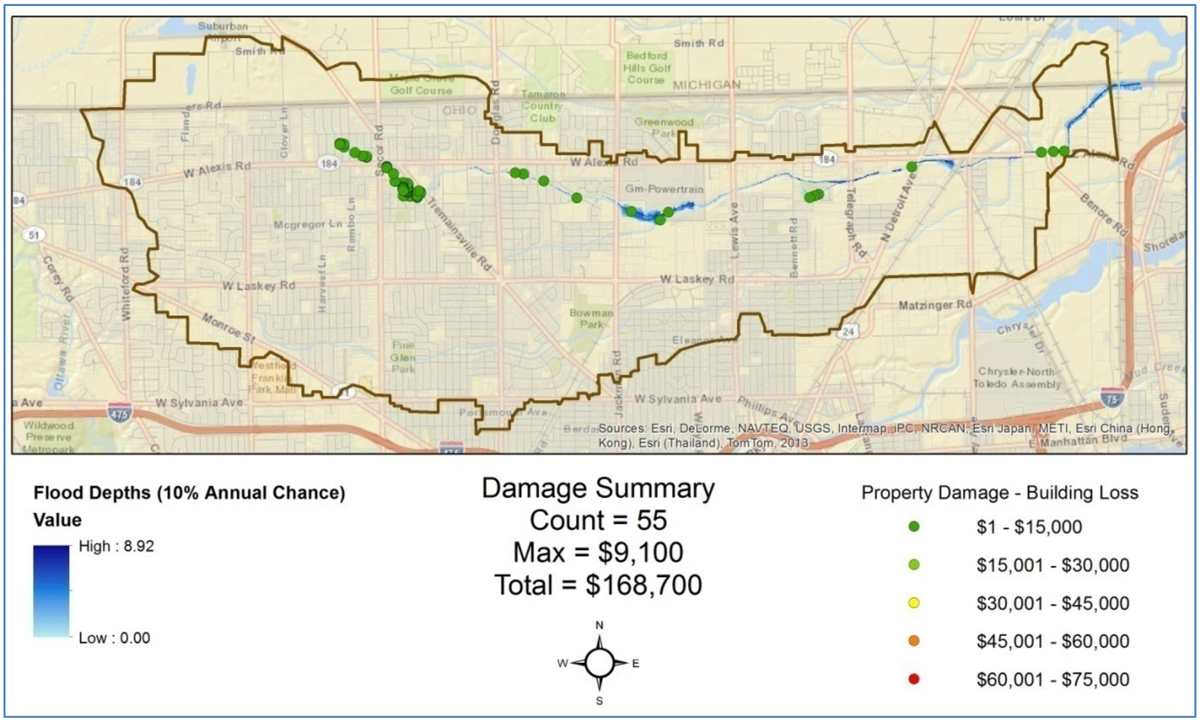


Figure 22. Silver Creek Current Land Use and Current Precipitation 10-year, 24-hour Storm Flooding Damages with Flood Storage

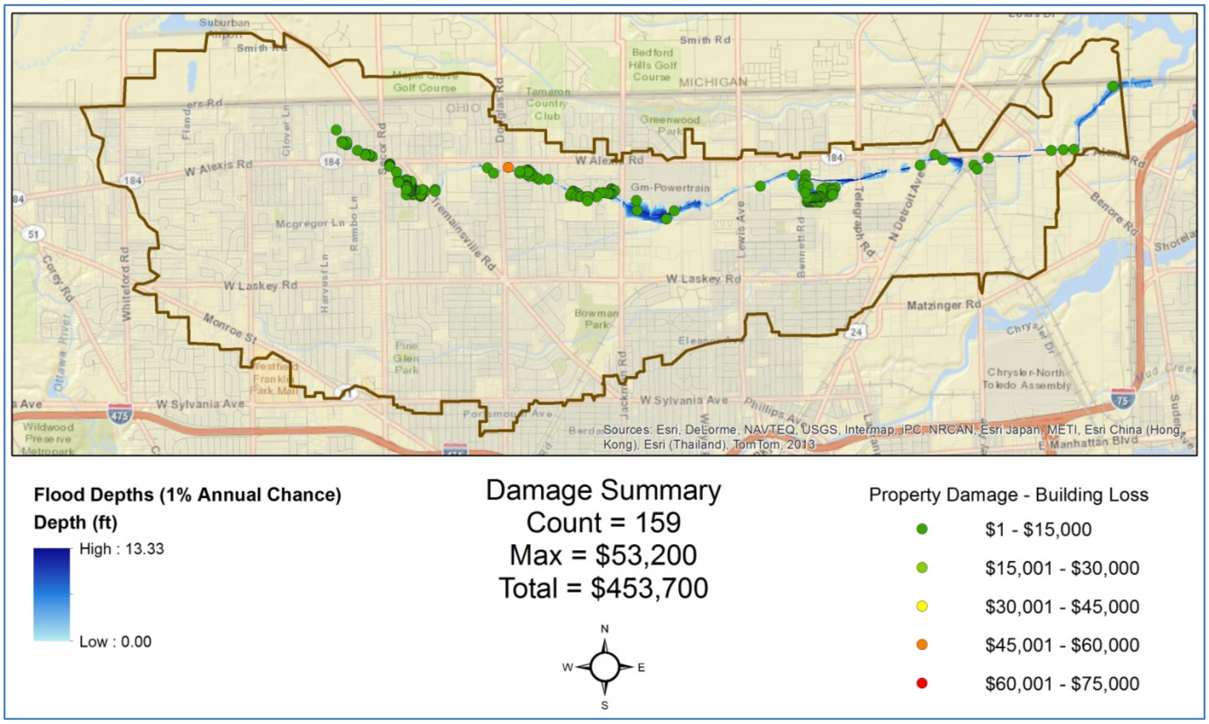


Figure 23. Silver Creek Current Land Use and Current Precipitation 100-year, 24-hour Storm Flooding Damages with Flood Storage

Reducing the peak discharge by 10 percent at River Station 8071 resulted in a 30 to 44 percent reduction in total structural flood damages for various storm events (see Table 12). The same peak discharge reduction also resulted in 19 to 37 percent fewer structures being damaged in a storm event (see Table 12).

Table 12. Silver Creek Flooding Damages for Current Land Use and Current Precipitation with Flood Storage

Recurrence Interval	Number of Buildings Damaged	Maximum Single Building Damage ($)	Total Damage for all Buildings ($)	Mean Damage Per Building ($)	Number of Buildings Damaged Percent Change (from Scenario 1)	Total Damage Percent Change (from Scenario 1)
2-year	13	$5,900	$33,000	$2,500	-35%	-38%
5-year	31	$8,100	$100,400	$3,200	-34%	-44%
10-year	55	$9,100	$168,700	$3,100	-19%	-32%
25-year	64	$29,500	$232,400	$3,600	-27%	-30%
50-year	96	$52,200	$326,800	$3,400	-36%	-30%
100-year	159	$53,200	$453,700	$2,900	-37%	-39%

Source: Hazus.

3.7 Modeling Scenario 4: Future Land Use and Future Precipitation with Flood Storage

The goal of scenario 4 is to look at how the community could reduce flooding damage under future conditions if a 10 percent increase in flood storage was provided. In scenario 4, all of the land use and precipitation assumptions are the same as in scenario 2. The difference in this scenario is that it is assumed that peak discharges are reduced by 10 percent at River Station 8071 through the implementation of stormwater management and GI upstream. A 10 percent reduction in peak discharge correlates to an associated storage volume of runoff. This scenario looks at how the community could reduce flooding damage under future conditions if a 10 percent increase in flood storage was provided.

3.7.1 H&H Results

Flood Storage Volume = (1,318 ft^3/sec - 1,187 ft^3/sec)(3 hours)(60 sec/min)(60 min/hr)(acre/43,560 ft^2) = 33 acre-feet. It was assumed that the peak flow is reduced by 10 percent for three hours. The three hour reduction time was chosen based on engineering judgment and is somewhat arbitrary; however, it does provide an order of magnitude estimate of the storage volume needed for peak flow reduction.

The 100-year, 24-hour peak discharge at River Station 8071 in Silver Creek is 1,318 cfs under scenario 2. That flow was reduced by 10 percent to 1,187 cfs for the scenario 4 analysis. Reducing peak discharges by 10 percent lead to a four to five percent decrease in velocity for all storm events (see Table 13). A 10 percent peak discharge reduction for scenario 4 is equal to 33 acre-feet of flood storage. This means that if a community wanted to reduce peak discharges by 10 percent during a 100-year, 24-hour storm event in 2035, 33 acre-feet of storage would need to be provided upstream of River Station 8071.

Table 13. Silver Creek Peak Discharges and Velocities for Future Land Use and Future Precipitation with Flood Storage

Recurrence Interval	Peak Discharge (cfs)	Velocity (ft/s)	Percent Change from Future Peak Discharge (Scenario 2)	Percent Change from Future Velocity (Scenario 2)
2-year	473	2.10	-10%	-5%
5-year	666	2.43	-10%	-5%
10-year	846	2.73	-10%	-5%
25-year	943	2.87	-10%	-5%
50-year	1057	3.02	-10%	-4%
100-year	1187	3.16	-10%	-5%

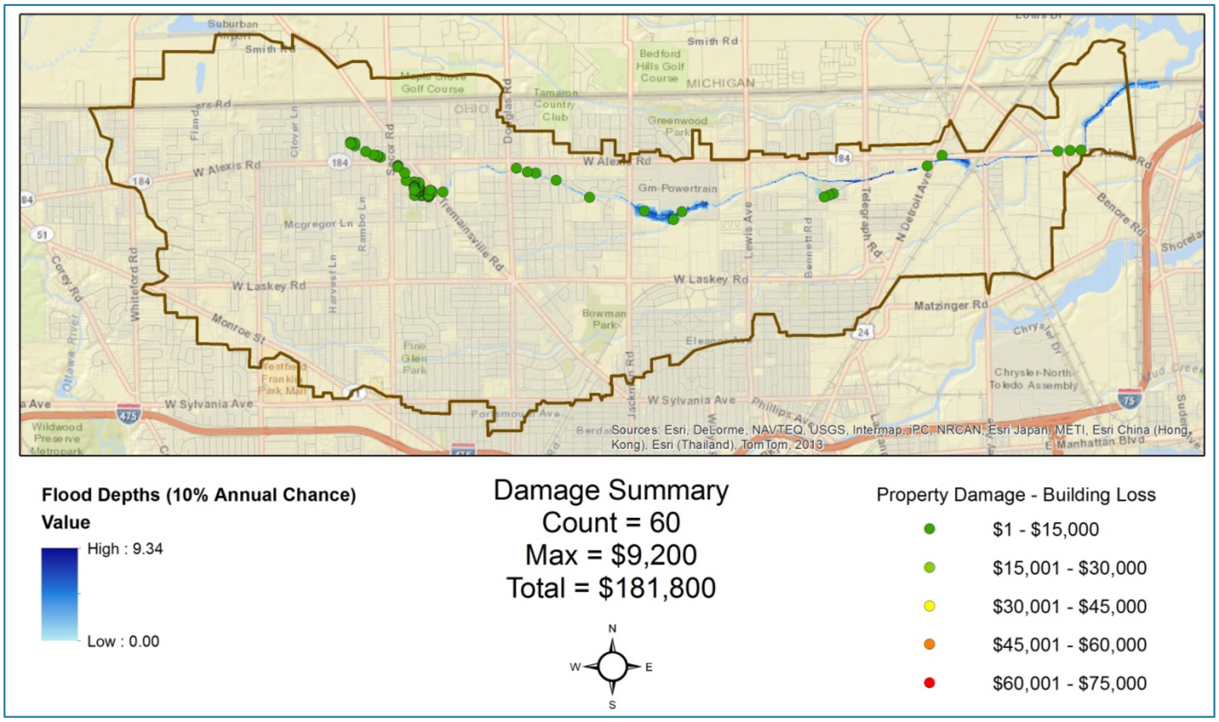
Source: Data calculated using USGS regression equation.

Reducing peak discharges and accounting for 33 acre-feet of storage changes the flood depth grids generated by HEC-RAS. HEC-RAS was re-run assuming that 33 acre-feet of storage was added, which resulted in depth grids for the Silver Creek sub-watersheds that represent flooding when storage is provided under future land use and precipitation conditions.

3.7.2 Hazus Results

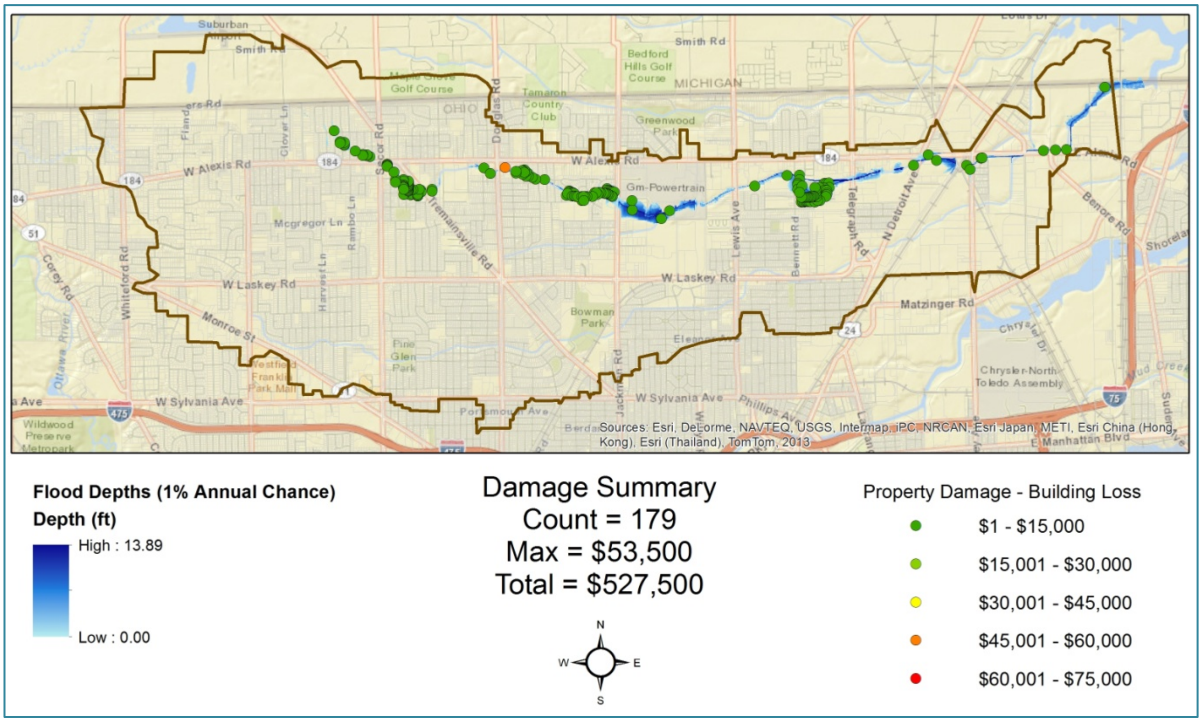
Hazus was used to estimate flood damages to buildings within the Silver Creek watershed based on the flood depth grids developed through H&H modeling of the future land use and future precipitation scenario with a 10 percent reduction in peak discharge flows (i.e., 33 acre-feet of storage). Hazus assumptions in scenario 2 are the same for scenario 4.

Reducing the peak discharge with the implementation of GI reduces the flood losses. It was estimated that 60 structures in Silver Creek were damaged, totaling $181,800 in costs during the 10-year, 24-hour storm event under future precipitation conditions with the implementation of GI (see Figure 24). It was estimated that 179 structures in Silver Creek were damaged, totaling $527,500 in costs during the 100-year, 24-hour storm event under future precipitation conditions (see Figure 25).



Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

Figure 24. Silver Creek Future Land Use and Future Precipitation 10-year, 24-hour Storm Flooding Damages with Flood Storage



Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

Figure 25. Silver Creek Future Land Use and Future Precipitation 100-year, 24-hour Storm Flooding Damages with Flood Storage

Reducing the peak discharge by 10 percent at River Station 8071 resulted in a 21 to 50 percent reduction in total building flood damages for various storm events (see Table 14). The same peak discharge reduction also resulted in 19 to 39 percent fewer structures being damaged in a storm event (see Table 14).

Table 14. Silver Creek Flooding Damages for Future Land Use and Future Precipitation with Flood Storage

Recurrence Interval	Number of Buildings Damaged	Maximum Single Building Damage ($)	Total Damage for all Buildings ($)	Mean Damage Per Building ($)	Number of Buildings Damaged Percent Change (from Scenario 2)	Total Damage Percent Change (from Scenario 2)
2-year	13	$6,100	$35,300	$2,700	-32%	-50%
5-year	37	$8,700	$124,100	$3,400	-27%	-30%
10-year	60	$9,200	$181,800	$3,000	-19%	-34%
25-year	77	$47,400	$281,500	$3,700	-26%	-21%
50-year	108	$52,800	$352,100	$3,300	-35%	-32%
100-year	179	$53,500	$527,500	$2,900	-39%	-46%

Source: Hazus.

3.8 Flood Storage with GI

As was shown in the assessments in Sections 3.6 and 3.7, providing a 10 percent reduction in peak discharge through flood storage has a beneficial impact by reducing flood damages. A 10 percent reduction in peak discharge is equivalent to 31 acre-feet under current conditions and 33 acre-feet under future conditions (see Table 15).

Table 15. Silver Creek Storage Volumes for the 100-year, 24-hour Storm Event

Scenario	Percent Reduction in Peak Discharge	Storage Needed (acre-feet) to Achieve Percent Reduction in Runoff Volume
1. Current Land Use/ Current Precipitation	10%	31
2. Future Land Use/Future Precipitation	10%	33

Source: Data calculated using USGS regression equation.

Flood storage can be achieved in a variety of ways. The type of GI implemented on a site depends on factors such as:

- Site hydrology (permeability, soil, slope, ground cover).
- Available open space.
- Community preference/acceptance.
- Presence of underground of obstructions such as utility lines or natural features such as public shade trees.

- Cost.

In order to achieve approximately 30 acre-feet of flood storage, a variety of GI could be implemented on multiple sites. Many types of GI practices can be designed to have small-scale applications, which is advantageous because they can be implemented as a retrofit or as part of new construction on almost any property. There are multiple ways that a community can mix and match different types of flood storage options in order to achieve the necessary acre-feet of storage. Each community will need to determine the best combination of practices and sites.

In the Silver Creek watershed, some specific GI opportunities were identified. Those opportunities include:

- Installing bioretention in the form of bioswales along the approximately 70 miles of unimproved roadway. These projects can be sequenced over a 20-year period and synchronized with roadway improvements to reduce costs.
- Working with local industries to install blue roofs on large commercial buildings, which are estimated to have roof areas totaling 2.5 million square feet within Silver Creek.
- Installing permeable pavement where sidewalks or bikeways need to be replaced or built.
- Installing underground storage beneath parking lots, roadways, and other developed areas.
- Installing stormwater tree trenches along existing and new sidewalks as they are built or as opportunities arise.
- Installing stormwater retention ponds in open areas.
- Building an extended detention wetland in the upstream portions of the watershed.
- Consider buyouts (two buy-outs have occurred in the past) of chronic flood areas, possibly in conjunction with installing GI to increase flood storage on the approximately 7.8 acres of tax-forfeited parcels in the watershed. There may be opportunities to examine the connectivity of these areas to design community co-benefits such as public open space, bike paths, walkways, or community gardens into the design.

Cost is a large factor to consider when deciding what GI practices should be implemented on a site. In general, GI costs vary widely between geographic areas and are extremely site-specific. The project team performed a literature review of available GI costs nationwide (see Table 16). The team looked at both capital and operations and maintenance (O&M) costs per square foot of surface area of the practice and per cubic foot of water storage of the practice.

Table 16. Green Infrastructure Estimated Unit Costs

	Capital Costs		Operations and Maintenance Costs	
GI Practice	Capital Cost per Square Foot of Surface Area Installed ($/SF)[1,2]	Capital Cost per Cubic Foot of Flood Storage Provided ($/CF)[1,2]	Annual O&M Cost per Square Foot of Surface Area Installed ($/SF/year)[1,2]	Annual O&M Cost per Cubic Foot of Flood Storage Provided ($/CF/year)[1,2]
Bioretention/Bioswale	26.0	21.2	0.9	1.3
Blue Roofs	4.0	6.0	0.2	N/A[3]
Permeable Pavement (Sidewalk)	7.6	16.8	0.02	N/A

GI Practice	Capital Costs		Operations and Maintenance Costs	
	Capital Cost per Square Foot of Surface Area Installed ($/SF)[1,2]	Capital Cost per Cubic Foot of Flood Storage Provided ($/CF)[1,2]	Annual O&M Cost per Square Foot of Surface Area Installed ($/SF/year)[1,2]	Annual O&M Cost per Cubic Foot of Flood Storage Provided ($/CF/year)[1,2]
Underground Storage[4]	N/A	41.3	N/A	1.3
Stormwater Tree Trench[5]	7500	N/A	N/A	N/A
Retention Pond	1.0	2.9	0.1	0.0
Extended Detention Wetland	2.6	1.3	0.03	N/A

Table Notes:

1. All costs are in 2012$.
2. Refer to Appendix C for a summary of sources for capital and O&M costs.
3. N/A indicates that costs were not available.
4. The cost per cubic foot of storage is anticipated to be lower. One case study used to find average costs had a significantly higher $/CF values, which greatly increased the overall average. The median cost for underground storage in 2012 dollars was $17.2/CF. Refer to Appendix C.
5. Tree trench cost is per unit rather than per square foot.

Another challenge with GI costs is that each practice has vastly difference design components, which makes a comparison between two GI practices difficult. The project team focused on manipulating the costs to reflect a constant variable between practices and chose cubic feet of runoff storage provided. Cost per square foot of practice is the most common unit found in case studies; however, a 100 square foot bioretention area could provide vastly different amounts of flood storage depending on its designed depth. Additionally a 100 square foot bioretention area is not comparable in flood storage to 100 square feet of blue roof. The constant variable chosen in order to equalize all GI practices was cubic feet of runoff storage provided. Utilizing a cost per cubic foot of storage allowed the GI practices to be compared relative to each other.

Based on the team's research, the various types of GI practices could be organized by costs relative to one another (see Table 17). Stormwater tree trenches were left out of this comparison because their costs are only available per unit and could not be compared to the surface area or storage area values used to compare the other GI practices. Additionally, some practices that did not have sufficient capital or O&M cost information were not able to be included in the comparison.

Table 17. Relative Green Infrastructure Costs

	Capital Cost per Square Foot of Surface Area Installed	Capital Cost per Cubic Foot of Flood Storage Provided	Annual O&M Cost per Square Foot of Surface Area Installed	Annual O&M Cost per Cubic Foot of Flood Storage Provided
Most Expensive	Bioretention	Underground Storage	Bioretention	Underground Storage
	Permeable Pavement	Bioretention	Blue Roof	Bioretention
	Blue Roof	Permeable Pavement	Retention Pond	Retention Pond
	Extended Detention Wetland	Blue Roof	Extended Detention Wetland	
	Retention Pond	Retention Pond	Permeable Pavement	
Least Expensive		Extended Detention Wetland		

The GI costs relative to one another are also shown in Figure 26 and Figure 27. In general bioretention, underground storage, and permeable pavement tend to be more expensive than blue roofs, extended detention wetlands, and retention ponds. When considering which GI practices to implement in large quantities, communities should consider the options that provide the most return on investment with regards to flood storage volumes. In order to maximize the cost-benefit of implementing GI, the community should consider economies of scale, sequencing, leveraging other infrastructure investments and mixing and matching various practices to achieve the total acre-feet of storage desired.

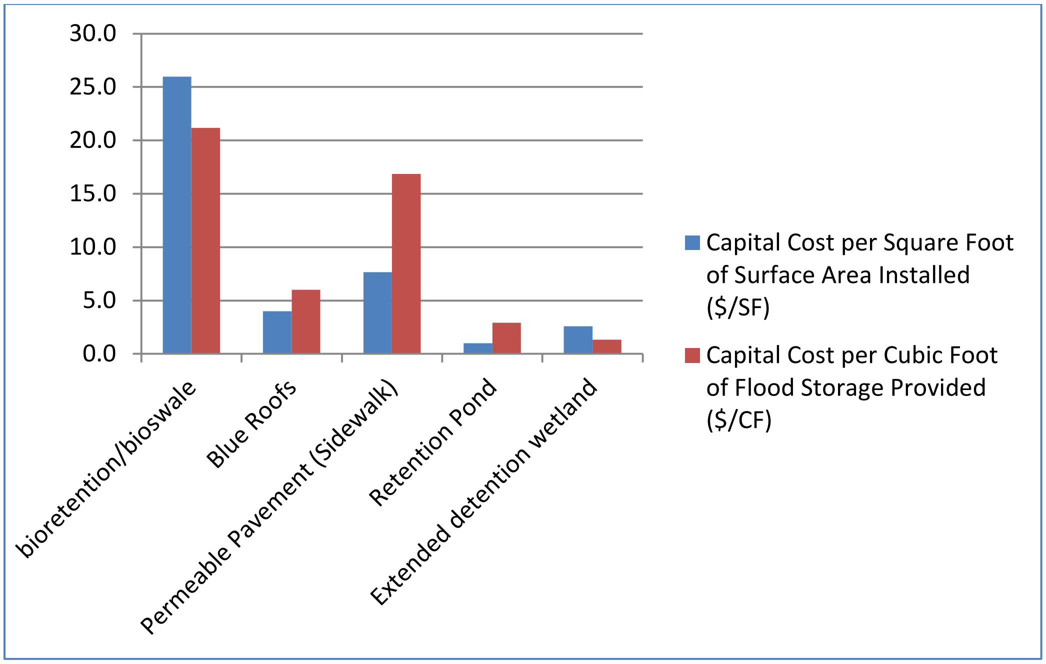


Figure 26. Relative Green Infrastructure Capital Costs

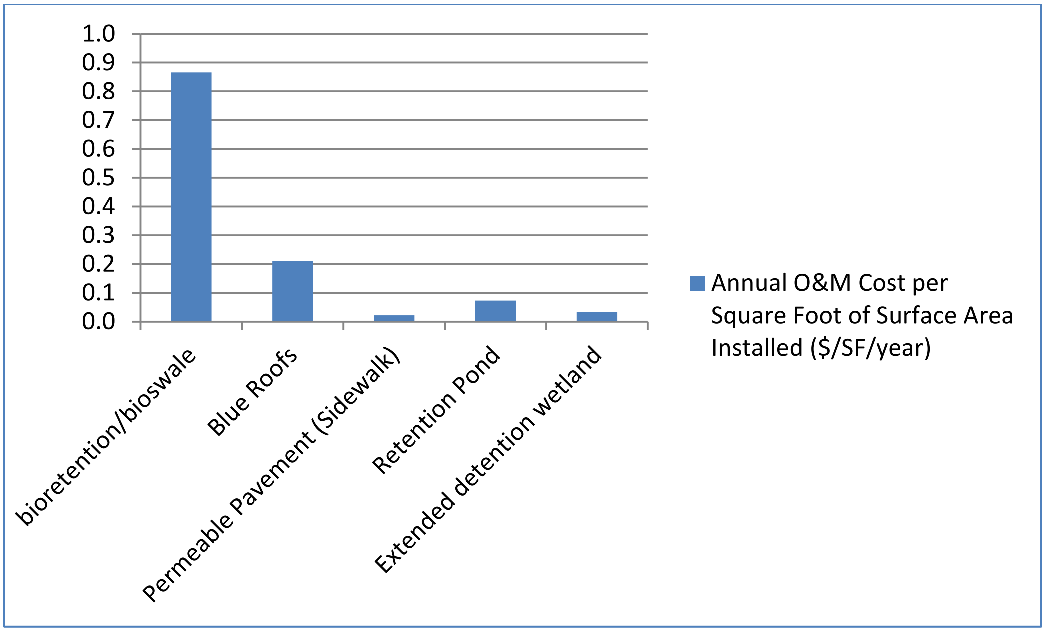


Figure 27. Relative Green Infrastructure O&M Costs

The cost of using GI to provide 31 acre-feet of storage in Toledo varies greatly depending on which practices were chosen. If 31 acre-feet of storage was provided with only extended detention wetlands (the least expensive GI practice) at $1.30/CF then the total implementation cost would be $1,755,468. If 31 acre-feet of storage was provided with only underground storage (the most expensive GI practice) at $41.30/CF then the total implementation cost would be $55,769,868. This is a very large range of estimated implementation costs but gives a starting point for communities to think about and encourages the implementation of GI practices that provide more storage for less capital costs.

To estimate the cost of GI, the community would multiply the unit cost of the type of GI times the volume of flood storage needed. If 31 acre-feet of storage was provided by constructing extended detention wetlands at a unit cost of $l.30 per cubic foot, it would cost: $1.30/ft ^{3} *x 43,560 ft*^{2}*/acre x 31 acre-feet = roughly $1,750,000. If 31 acre-feet of storage was provided by installing underground storage at a unit cost of $4l.30 per cubic foot, it would cost: $41.30/ft* ^{3} *x 43,560 ft*^{2}*/acre x 31 acre-feet = roughly $55,800,000.*

Toledo can begin estimating what it would cost to implement the different GI practices in identified locations where opportunities exist. For example, it is estimated that within Silver Creek there is at least 2.5 million square feet of commercial roof space. The following steps could be taken to estimate the costs of blue roof implementation and the storage that could be obtained:

- 2,500,000 ft^2 of commercial rooftops in the Silver Creek watershed.
- Assume 6” depth.
- Assume 75% of roofs could be retrofit with blue roofs.
- Total Storage = 2,500,000 ft^2*0.75*0.5 ft = **937,500 ft^3**

- 937,500 ft^3/43,560 ft^2/acre = **21.52 acre-feet**
- 937,500 ft^3*\$6/ft^3 = **\$5,625,000 → \$261,360 per acre-foot**

3.9 Summary of Benefit Analysis

The amount of reduced damages associated with flood mitigation strategies is represented as "benefits" (i.e., the difference between the economic impact of flooding without flood mitigation and those impacts with the implementation flood mitigation infrastructure). These economic benefits will likely be widespread; however, due to data limitations, only the largest benefit of flood mitigation in Toledo is quantified: reduced building damages. Reduced building damage is only one component of the overall benefits provided by flood storage provided by implementing GI. Other potential benefits such as improved water quality, increased habitat, increased green space, reduced infrastructure damage, reduced land damage, and increased property values are important to consider, but were not able to be monetized in this study (Appendix B).

EAD and the PV of the benefit of reduced building damages are assessed over 20 years. When evaluating the costs and benefits of investing in flood mitigation in Toledo it is important to keep in mind that the estimated benefits are an underestimate of the true benefits since many benefits are not monetized. The PV of benefits from avoided building damage is estimated to be approximately \$700,000 (roughly \$38,000 annually). The expected annual benefits increase over this 20-year period because the expected damages of storms will increase as expected precipitation increases. See Appendix D for annualized benefits.

The benefits calculated in this assessment are predicted to be much lower than those that would actually be provided for two main reasons: 1) additional benefits outside of avoided building damages were not monetized and 2) the benefit analysis ended at 20 years. Because non-monetized benefits such as increased habitat and improved water quality were not included in this study's assessment, the calculated benefits are likely to be greatly underestimated. Not all benefits are tangible and placing a value on an intangible benefit is difficult and subjective. It should be understood that the GI recommended in this study provides numerous benefits outside of the costs avoided from building damage. These non-monetized benefits should be acknowledged and considered by the community so that they are at least qualitatively incorporated into any cost-benefit analysis.

Additionally, many GI practices have benefits that continue beyond a 20-year time period. Ending a benefit analysis at 20 years assumes that at year 21 the benefit is zero dollars, which is not true for many GI practices. Because the economic benefit analysis in this study only went out 20 years, the overall benefits are further underestimated. Communities may want to consider longer benefit timelines in order to more accurately reflect the benefits provided by GI throughout its entire life cycle. If these benefits were extended to reflect a 50-year period, the PV would increase from \$698,539 to \$1,769,644 (roughly a 150% increase since the number of years considered increases by 150% and the benefits do not exhibit diminishing returns).

3.10 Comparison of Benefits and Costs

Although we do not know the true benefits and costs associated with implementing GI in Toledo, the previous two sections have presented some analysis of benefits and costs, which can be compared to demonstrate how the city may conduct a benefit-cost analysis. In Section 3.8, the cost of obtaining 31 acre-feet of storage using the least expensive GI practice, extended detention wetlands, was calculated to be $1,755,468. If a third of these costs were incurred in years two, four, and six of the analysis, then the PV of the cost would be $1,700,543 (Appendix D). This PV of cost occurs regardless of whether a 20-year of 50-year time horizon is considered since all costs are incurred in the first six years. In Section 3.9, the PV of benefits associated with reduced building damages over 20 years was estimated to be $698,539; over 50 years the benefits would be $1,769,644.

However, when comparing the above benefits and costs it is important to keep in mind that these values may not reflect the true benefits and costs to the city. Federal funds, state funds, or grants may also be available for green infrastructure construction, which would reduce the cost to the city. The true benefits are greater than the estimated benefits since many benefits are not monetized. In addition, the cost per unit of GI may vary significantly. The city needs to proceed from planning scale to design scale to calculate site-specific costs. As shown in Table 16, there is a wide range of costs depending on the type of GI implemented. To minimize costs, the city can focus on cheaper solutions and sequence them to coincide with other capital projects or funding sources to reduce marginal costs. Additionally, the city must consider the lifespan of the GI project as an important factor in determining the timeframe over which to compare benefits and costs.

If benefits and costs over the 20-year time are compared, the costs ($1.7 million) exceed the calculated benefits ($700,000). However, when the time horizon is extended to 50 years the costs remain constant at $1.7 million but the benefits grow to $1.77 million. In this comparison, benefits exceed costs, providing evidence in favor of implementing the GI project, thus demonstrating the importance of determining the appropriate time horizon when calculating benefits and conducting a benefit-cost analysis.

3.11 Policy Options

As this analysis has shown, flooding can be mitigated through the implementation of GI, but this is just one tool that should be considered in the larger context of community land use and sustainability planning. Flooding can be worsened, negating gains made by implementing mitigation options, if preventing future flooding is not also part of the agenda. Thus, future development and, importantly, redevelopment patterns in Toledo (in general) and in Silver Creek watershed (in particular) are critical decisions that will impact future flooding. In the case of Toledo, which is largely built out, those decisions come primarily in the form of redevelopment—including where further density should be encouraged, how it is designed, where open spaces should be reclaimed, and where flood storage function should be restored and enhanced. All of these issues fall into the category of land use considerations. Although the project team suggested some of these approaches in community meeting, they were not the focus of our analysis. Thus, we remind our community partners to consider these in the course of their discussions about sustainability planning.

A wide variety of adaptive land use practices, policies, tools, and strategies are available to communities interested in planning for sustainable flood management. See Appendix B for a more complete listing of strategies that can be considered. The following options were discussed for consideration in Toledo.

Urban Form Requirements: One policy option to reduce building damage would be to implement "urban form" requirements (which help shape and structure the future of the city) for development in critical flood storage areas. Such requirements could dictate that structures have floodable first floors (e.g., parking garage, structures elevated on stilts, no critical utilities in basements).

Buy-outs: Toledo has purchased homes as part of buy-out strategies in 2002 and 2006, so there is a history of using this method to remove chronically flooded properties from harm's way. The city of Toledo estimated the average residential buy-out costs at $87,000 per home for property purchase and creation of green space. When considering that this cost provides flood mitigation for the future *and* reduces repeated flood damages (and insurance claims) to properties, this option may compare very favorably to other options. The disadvantage of this particular approach is that the FEMA buy-out program tends to be reactive (after major flood damages have already occurred). To be more pro-active, the city of Toledo could identify potential buy-out locations that are proximate to other optimal siting factors for reclaiming open space and restoring flood plain function. For example, criteria could include proximity to existing open space, proximity to tax-forfeited parcels, flood damage history, suitability for flood storage, etc. In conjunction with this planning, open space public amenities (such as community gardens, bike/walk ways, pocket parks) could be integrated to enhance the neighborhood and provide co-benefits. A portion of the estimated $9 million annual collection of stormwater fees could be considered to support this effort (within the eligibility guidelines of the fund) to start building pieces of the plan to implement this vision so that when opportunities arise to leverage funds from other sources, such as FEMA, and make strategic purchase of land parcels, the city has done the preliminary planning to expedite the process.

Transfer of Development Rights (TDR): This is one tool that can transfer development density "credits" from one place (flood prone areas) to other areas that are more suitable for higher density development, for example, less flood-prone areas (and areas that can otherwise support additional development and redevelopment). By shifting development away from existing and future flood hazard areas and conserving those areas to restore their function for flood storage (floodplains), the city can realize several benefits. By reshaping development patterns for more open space along creeks and their associated floodplains, the city can provide opportunities for co-benefits such as improving water quality, creating open space corridors along streams and rivers for wildlife and fisheries, and utilizing these areas for multiple uses such as bikeways, parks, and walkways. This can also reduce flood damage costs by avoiding development in harm's way. More sophisticated forms of TDR include a "Density Transfer Charge," where money is deposited into a fund dedicated to purchasing easement, abandoned property, or development rights in the flood plain. The account can become self-sustaining, in the form of a revolving fund. For more information about components of successful TDR programs, see Appendix E.

A larger area than the Silver Creek watershed (such as citywide) would be most appropriate for consideration of the above policies and could be done in conjunction with the city's sustainability and climate adaptation planning.

Stormwater Ordinance Revisions: Toledo's stormwater ordinance could be examined for possible modifications to more aggressively reduce runoff and increase flood storage. The city's stormwater credit manual is in the process of being updated. Opportunities for revision include: incorporating best practices that have worked elsewhere; considering options such as impact fees for impervious cover (if this is not already required); and encouraging innovative design (such as LID) or onsite retention as conditions of permitting for new construction or redevelopment.

Some recommendations that the project team made to Toledo at community meetings included: conducting more outreach/awareness building on the existing stormwater credit program to developers since many developers do not know it exists, raising the baseline standard to qualify for credits, and adding specifications for green practices and guidance on how to design and build GI methods. The stormwater utility could also become more actively involved in helping fund projects and providing incentives. In this way, new development, including redevelopment, could make more of a positive impact on reducing stormwater runoff.

3.12 Toledo Conclusions

The comparison of current precipitation to future precipitation indicates that precipitation is expected to increase along with flooding damages in the Silver Creek watershed over the next 20 years. The following strategies are recommended to reduce flooding damages in the future:

- Look for opportunities to increase flood storage and reduce runoff with green infrastructure:
    - Identify areas where the flood plain can be restored or new flood retention areas can be created within existing open space (e.g., tax-forfeited parcels).
    - Identify commercial/industrial rooftop areas that may be suitable for blue roofs.
    - Incorporate into roadway capital improvement plans the use of pervious pavement.
    - Incorporate into roadway capital improvement plans the use of curb cuts to direct runoff into vegetated islands and vegetated strips rather than into storm drains.
    - Install bioretention areas and swales, particularly along unimproved streets.
- Remove buildings from the flood plain where flooding is severe (buy-outs) and consider doing so in combination with other land use strategies such as strategic purchase of tax forfeited parcels, transfer of development rights or other mechanisms to shift development density away from the most flood-prone areas and into other areas more suitable for sustainable development while restoring flood storage function.
- Optimize community acceptance of GI by building on past successes and showcasing benefits (e.g., previously installed bioretention areas).
- Look for opportunities for co-benefits of GI:
    - Create recreational trails along water features.
    - Create parks and open space on buy-out parcels.
- Consider revising stormwater standards to incorporate more stringent requirements for onsite retention through revised policies.

As a next step and follow-on to this project, it is recommended that Toledo refine the watershed-level analysis from this study and begin to hone in on specific locations and GI practices that can be implemented in the Silver Creek and other watersheds. A more refined analysis would include developing site-specific concept plans, calculating stormwater runoff reductions, estimating the cost of implementation for chosen GI practices, and developing a 20-year implementation plan that takes advantage of economies of scale and leveraging other capital improvement projects.

4.0 DULUTH, MINNESOTA

The Chester Creek watershed was chosen as the study area in Duluth, Minnesota. Community background information and a summary of results from the modeling scenarios to determine expected impacts are presented below.

4.1 General Statistics and Land Use Background

The city of Duluth, Minnesota, is in St. Louis County (see Figure 28). St. Louis County occupies approximately 6,247 square miles and Duluth occupies approximately 67.79 square miles.[44] Approximately 86,211 people lived in Duluth in 2012,[44] and its population has remained relatively flat since 2000. Duluth's estimated median household income was $40,940 in 2011, up from $33,766 in 2000. The estimated median house or condo value was $149,100 in 2011, up from $80,700 in 2000.[45]

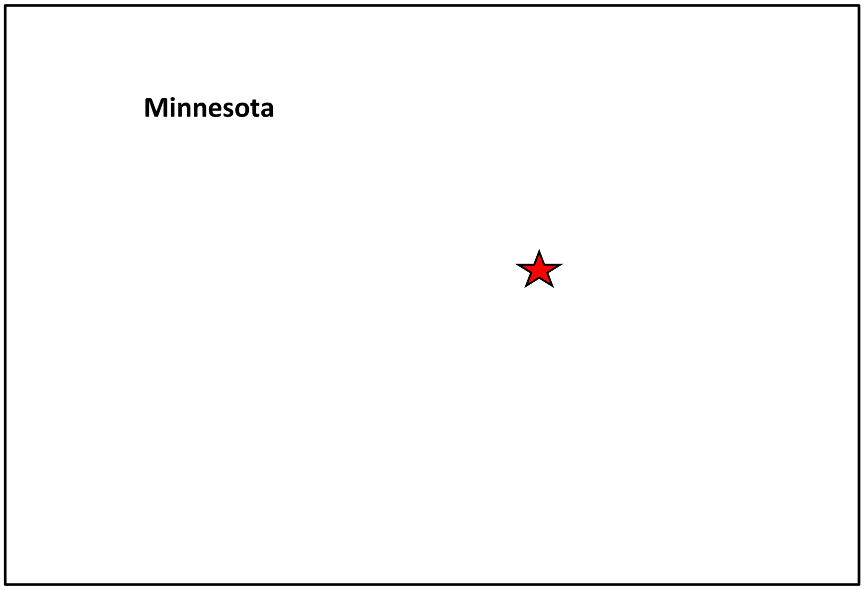


Figure 28. State of Minnesota Map

According to Duluth's Comprehensive Plan (2006)[46] the city is refocusing its local and regional economy on "natural resource assets as a defining element of its community character." The Comprehensive Plan indicates a desire to guide growth and development and strategically direct infrastructure investment choices given scarce financial resources. Thus, this GI study is very relevant to and timely for Duluth's consideration.[46]

Demographics in Duluth have shifted from developed areas to undeveloped areas: "Duluth's housing and population growth in the 1990s did not occur uniformly across the city. The 2003 Demographics report noted that of the 42 census tracts that comprise Duluth, only 17 had an increase in population, and only 11 increased by more than three percent. An analysis of population change by census tract portrays a similar picture. Most of the neighborhoods below the ridge lost

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[44] U.S. Census Bureau. State and County Quick Facts: Duluth, Minnesota. Retrieved from http://quickfacts.census.gov/qfd/states/27/2717000.html.

[45] Duluth, Minnesota City Data. Retrieved from http://www.city-data.com/city/Duluth-Minnesota.html#ixzz2iDJSE9yu.

[46] City of Duluth Comprehensive Plan. (2006). Retrieved from https://www.duluthmn.gov/planning/comp_plan/.

population or remained stable. Most of the growth occurred in neighborhoods in the far west and farther up the ridge or over the ridge. Growth areas tend to be the neighborhoods with land that could be developed for residential housing."

Duluth's land area is often referred to as either "above the bluff (or ridge)" or "below the bluff." The headwater watershed area above the bluff is characterized by relatively flat topography. The bluff transition zone is characterized by a very steep drop in elevation and deeply entrenched streams, sometimes referred to as "ravines." Several tributary streams run through very steep ravines throughout the city before discharging into Lake Superior.

Since the city of Duluth updated its Comprehensive Plan in 2006, Mayor Ness has been reported to support growing Duluth's population to 90,000 by the year 2020.[47] Future land use plans in Duluth would accommodate additional development in undeveloped areas. If the past trends reported in the Comprehensive Plan continue, future development is likely to occur in headwater areas above the bluff. If not properly sited and mitigated, such development could significantly increase flooding in downstream areas by increasing impervious surfaces.

4.2 Watershed Selection and Characteristics

The project team discussed watershed selection during an in-person community meeting in Duluth in December 2012 and a virtual meeting in April 2013. While in Duluth, the project team toured areas within the city where there were flooding issues and opportunities to implement GI. A final decision to assess the Chester Creek watershed was made at the April 2013 meeting (see Figure 29). Some of the more important site selection criteria included:

- Damage from June 2012 storm.
- Future land use within the watershed.
- Available data for H&H modeling.

LiDAR data provided by the city of Duluth were rasterized into 20-foot gridcell ESRI GRID and used to further delineate sub-watersheds within Chester Creek. The delineated sub-watersheds provided for the calculation of drainage areas and flow change locations for use in the USGS regression equations and HEC-RAS model. The elevation data for Chester Creek were processed using the standard suite of hydrology tools available in ArcGIS ArcHydro toolbox, resulting in a total of five sub-watersheds and a combined drainage area of 6.68 square miles.

All peak discharges and velocities provided for Chester Creek are from River Station 6787 (see Figure 29). River Station 6787 was chosen as the best representative location for the Chester Creek watershed because it is located along the divide between the upland portion of the watershed (above the bluff) and the ravine portion of the watershed (below the bluff). The portion of Chester Creek that is above the bluff is a large, flat headwater area that has a shallower slope compared to the portion of Chester Creek that is below the bluff. Below the bluff, Chester Creek has a very steep topography. The ravine walls are very high and runoff from above the bluff is funneled into a narrow channel as it flows through the ravine. Chester Creek empties into Lake Superior in downtown Duluth. There is no floodplain in Chester Creek below the bluff because all runoff is contained within the ravine walls. Because the runoff is contained in the ravine, there is minimal property damage from overbank flooding but lots of damage to the drainage system and

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[47] Passi, Peter. (2012). Mayor Ness lays out plan to increase Duluth's population to 90,000. *Duluth News Tribune*. Retrieved from http://www.duluthnewstribune.com/event/article/id/219571/.

surrounding land due to erosion, bank failure, and high velocity/high volume flows that overwhelm the drainage system.

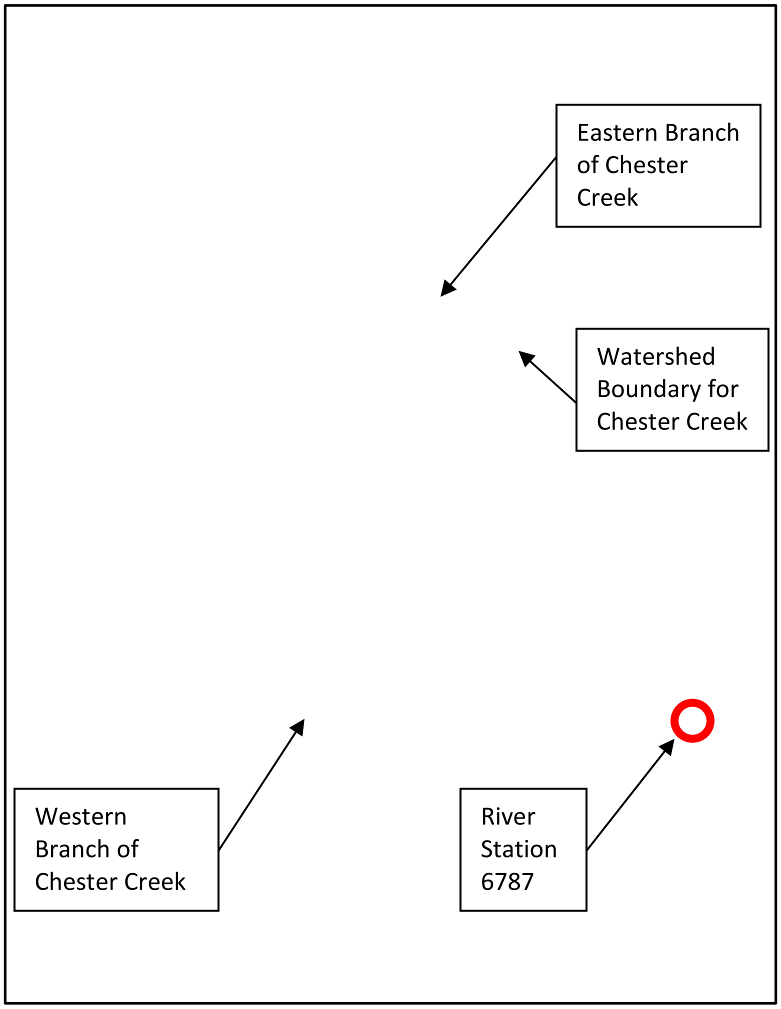

Figure 29. Chester Creek Watershed

Chester Creek is one of 23 major creek ravines in the city of Duluth. A prominent natural feature in Chester Creek watershed, Chester Creek Park, was acquired by the city in 1891 and additional acreage added in 1923.[48] Chester Creek Park includes a waterfall and recreational attractions. The Chester Creek watershed, especially the area above the bluff, has abundant open space, with only 24 percent of the watershed developed (see Figure 30).

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[48] Lake Superior Streams: Chester Creek History. Retrieved from http://www.lakesuperiorstreams.org/streams/chesterHistory.html.

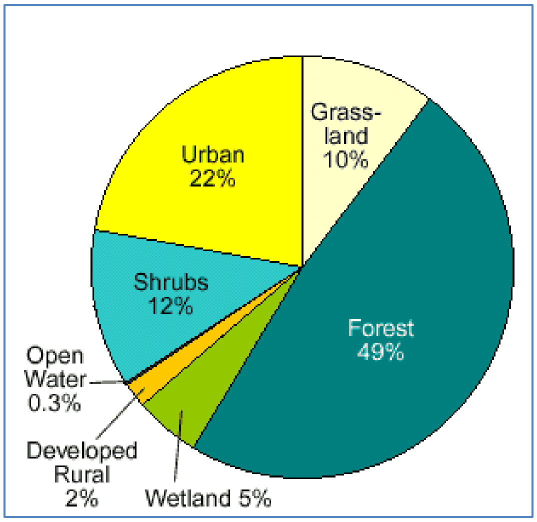

Figure 30. Chester Creek Watershed Land Use[49]

Current development in the Chester Creek watershed consists of mainly residential and mixed-use parcels (see Figure 31). Future development is planned in Chester Creek that will increase impervious areas in currently undeveloped parcels (see Figure 32). An increase in impervious area will reduce stormwater infiltration and increase surface stormwater runoff, which is likely to exacerbate flooding in the future unless aggressive stormwater mitigation requirements are implemented to offset increased runoff.

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[49] Lake Superior Streams: Chester Creek Watershed Land Use. Retrieved from http://www.lakesuperiorstreams.org/streams/chesterwshed.html.

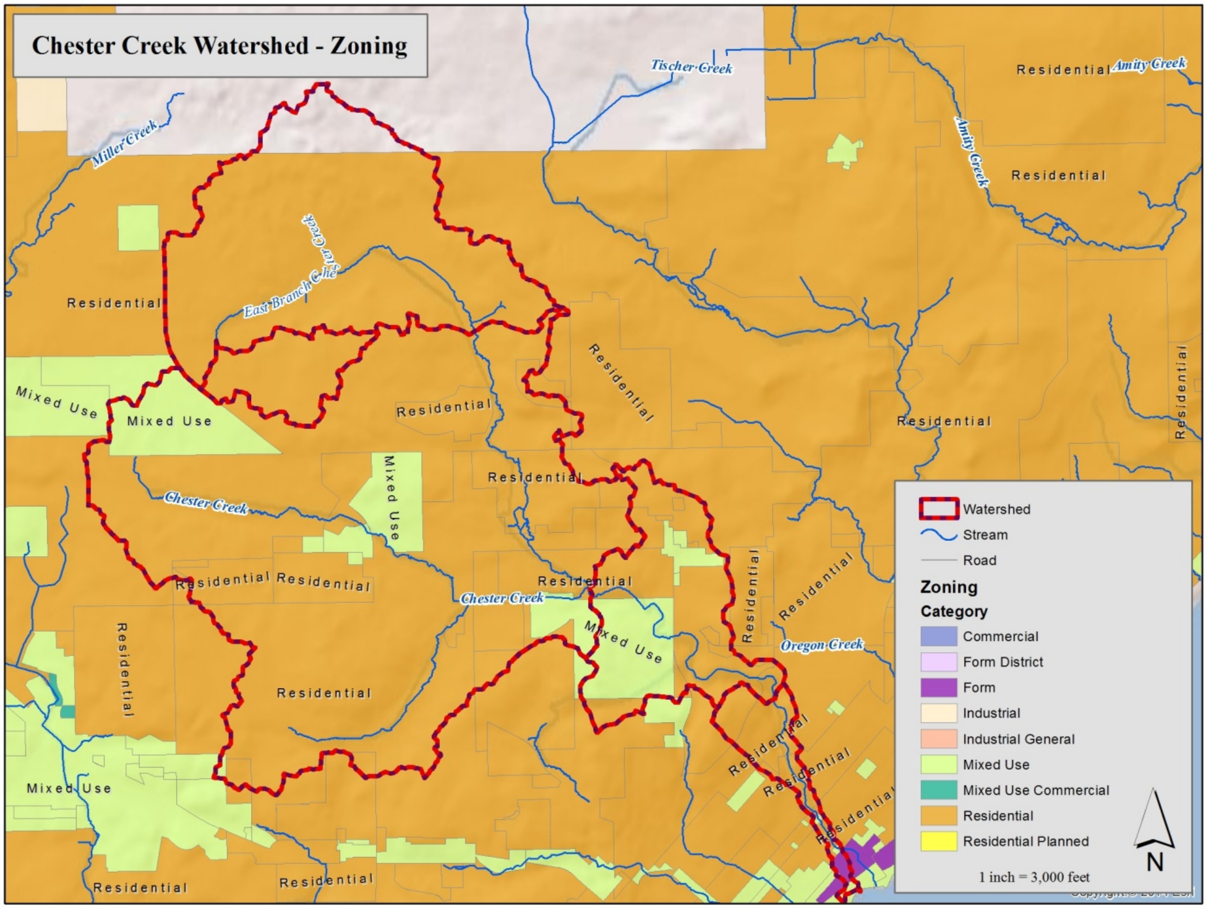


Figure 31. Chester Creek Watershed Current Land Use

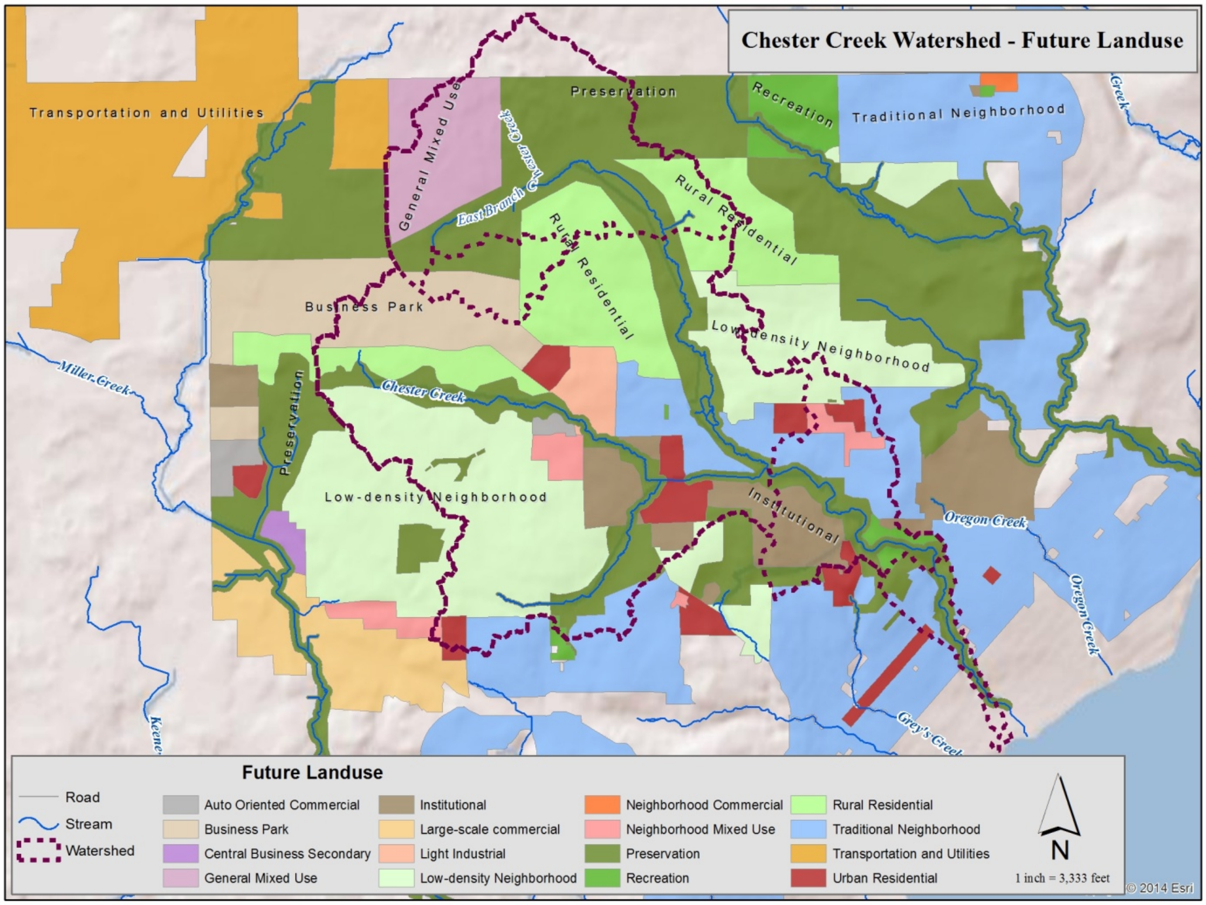


Figure 32. Chester Creek Watershed Future Land Use

Duluth experienced a severe storm event in June 2012 that caused significant damage. City personnel stated that the storm was considered a 500-year storm event by TP-40 standards and would be a 200-year storm event by Atlas 14 standards. According to NOAA's National Climatic Data Center, Duluth's June 2012 flood was caused by an intense precipitation event in which the city and surrounding communities received eight inches of rain and upwards of 10 inches in some areas in a 24-hour period. Stormwater runoff from this event caused widespread damage to natural resources and infrastructure (e.g., storm sewer pipes, bridges, roadways, sidewalks), with Duluth's rivers reaching their highest levels on record. The city of Duluth estimated that more than $55 million in damages to infrastructure occurred in 2012. According to the city of Duluth, Chester Creek damage totaled more than $1.7 million (see Figure 33). Most of the damage within the Chester Creek watershed was not incurred by structures such as buildings but rather by culverts and significant damage to its stream channel and adjacent land from the highly erosive streamflow velocities experienced during the storm. A challenge in the Chester Creek watershed was to determine how to reduce runoff velocities to prevent stream bank erosion and damage, in addition to providing flood storage to reduce flood volume. The project team determined early on that both issues needed to be addressed.

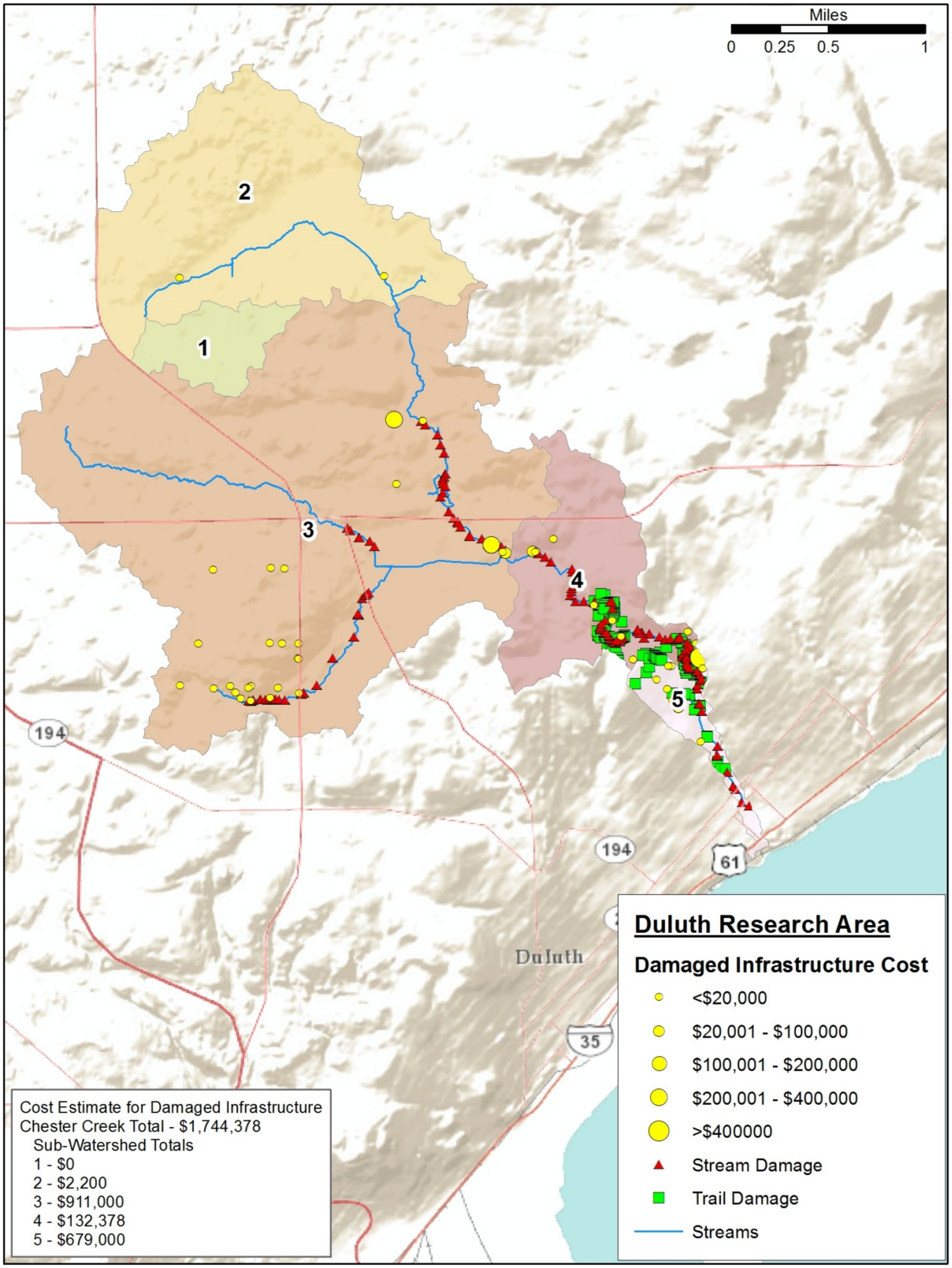


Figure 33. Chester Creek Damage from June 2012 Flood

4.3 Climate Modeling

CREAT was used to determine annual current (2013) and future (2035) precipitation values for this study. Historic climate data from CREAT were used to represent the current precipitation inputs and the historical average annual precipitation for Duluth is 30.4 inches. Current precipitation data used by CREAT for this project was from the Lake Superior Climate Station (see Figure 34).

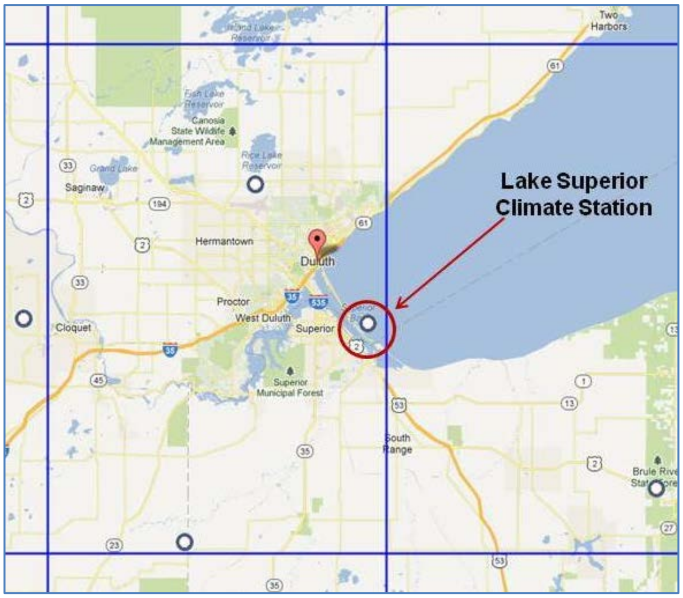


Figure 34. Duluth CREAT Climate Station

A variety of factors influences local precipitation patterns, but many climate science experts agree that in the future a significant amount of annual precipitation will likely come from intense or extreme rainfall events. According to CREAT outputs, projected changes in average annual precipitation vary widely from a 2.94 percent decrease to a 13.7 percent increase in Duluth (see Table 18). The projections in Table 18 are the range of values from the three CREAT model projections (hot and dry, central, and warm and wet). The warm and wet model projection was the climate scenario used to extrapolate precipitation data for Duluth in this study because it provides a worst-case scenario with the greatest increase in precipitation throughout the year.

Table 18. Duluth Climate Data Projections

Future Time Period	Climate Scenarios[a]	Percent Change in Average Annual Precipitation
2020 - 2050	Hot and Dry	-1.61%
	Central	2.48%
	Warm and Wet	7.49%
2045 - 2075	Hot and Dry	-2.94%
	Central	4.54%
	Warm and Wet	13.71%

Source: Data extracted from EPA’s CREAT.

Table Note a: For a detailed description of the methodology used to develop the future climate scenarios, please see the Methodology Guide within EPA’s CREAT software.

Climate projections extracted from CREAT for Duluth mirror the regional findings in the scientific literature illustrating an increase in intense precipitation events for the time periods of 2020 to 2050 and 2045 to 2075. Projections for Duluth show an increase in the frequency of the 100-year storm event (see Table 19). The 100-year storm event is used to describe a precipitation event that has a one percent probability of occurrence in any given year. The Duluth projections indicate a more significant increase in the 100-year storm event during the second half of the 21st century (2045 to 2075) than in the first half of the 21st century (2020 to 2050). The frequency of intense rain events, both 24-hour and multiday, will almost certainly continue to increase during the 21st century, which will subsequently increase the risk of flooding throughout Duluth's watersheds.[11]

Table 19. Duluth Projected Change in the Frequency of 100-Year, 24-Hour Storm

Climate Scenarios[a]	Time Period 2020 - 2050	Time Period 2045 - 2075
Hot and Dry	9.5%	17.3%
Central	0.5%	0.9%
Warm and Wet	8.8%	16.0%

Table Note a: For a detailed description of the methodology used to develop the future climate scenarios, please see the Methodology Guide within EPA's CREAT software.

It should be noted that the percent change in annual precipitation does not necessarily correlate with the same percent change in intense rainfall events. For example, intense and extreme rainfall events could increase at the same time that overall annual precipitation decreases and vice versa. Alternatively, it is possible that as intense precipitation events increase, the average annual precipitation will also increase. According to the CREAT data for Duluth, under the warm and wet model, both average annual precipitation and the frequency of the 100-year, 24-hour storm event will increase.

The resultant flooding from increased precipitation in Duluth may negatively impact the city's built and natural infrastructure, local industries, businesses, and human health. The projected increase in heavy precipitation events will likely impose a large burden on the city to improve stormwater runoff management techniques.

Sections 4.4 through 4.7 discuss the modeling in this study used to assess four different scenarios:

1. Current precipitation and current land use
2. Future precipitation and future land use
3. Current precipitation and current land use with provided flood storage
4. Future precipitation and future land use with provided flood storage

As is indicated from the CREAT data summarized in this section, precipitation is likely to increase in the future. Flooding is an issue in Chester Creek under current conditions, which means that an increase in precipitation will exacerbate the problem. An increase in precipitation not only leads to more flooding, but also means that the odds of incurring damages during high-precipitation events will increase. For example, assume that the storm at which damage occurs in Chester Creek is a 100-year storm event (i.e., a storm with a one percent chance of occurring in any given year) with a peak discharge of 1,530 cfs at River Station 6787. This means that under current conditions there is a one percent chance that a storm with a peak discharge of 1,530 cfs, which causes damage, would occur. In 2035 under the assumed future conditions, a peak discharge of 1,530 cfs at River Station

6787 has 1.84 percent chance of occurring rather than one percent (see Table 20). This means that under future conditions there is a 1.84 percent chance that a storm with a peak discharge of 1,530 cfs, which causes damage, would occur. The chance of having a storm that causes damage increases by 84 percent for the Chester Creek watershed.

Table 20. Frequency Increase of Peak Discharges

Scenario		Percent Chance[a] 424 cfs (current 2-year) Peak Discharge	Percent Chance 666 cfs (current 5-year) Peak Discharge	Percent Chance 905 cfs (current 10-year) Peak Discharge	Percent Chance 1,099 cfs (current 25-year) Peak Discharge	Percent Chance 1,313 cfs (current 50-year) Peak Discharge	Percent Chance 1,530 cfs (current 100-year) Peak Discharge
1	Current land use/ current precipitation	50.00%	20.00%	10.00%	4.00%	2.00%	1.00%
2	Future land use/ future precipitation	74.87%	33.28%	14.95%	7.80%	3.81%	1.84%
3	Current land use/ current precipitation/ flood storage[b]	34.00%	11.51%	3.95%	1.66%	0.64%	0.24%
4	Future land use/ future precipitation/ flood storage[b]	52.49%	19.05%	7.00%	3.11%	1.27%	0.51%

Source: Data calculated using USGS regression equation.
Table Notes:
a. The percent chance in any given year.
b. Flood storage for Chester Creek is assumed to be 20 percent of flow from current conditions.

Ultimately, an increase in precipitation and impervious area leads to an increase in the frequency of damaging storm events occurring. Assessing how the frequency of damaging storm events will change under different precipitation and land use assumptions is a powerful tool that communities can use to help mitigate flooding and plan for the future. Table 20 shows that increasing flood storage under scenarios 3 and 4 reduces the frequency of receiving a peak discharge that causes damage.

4.4 Modeling Scenario 1: Current Land Use and Current Precipitation

4.4.1 H&H Results

A USGS regression equation was used for the hydrology modeling to calculate the peak discharge of the sub-watersheds within Chester Creek. Elevation data for the study area was obtained from the local sponsor in the form of elevation contours. These contours were used to create an elevation raster (ESRI GRID) with a 20-foot grid cell size. The elevation grid was used to delineate sub-watersheds for the Chester Creek watershed by using the standard suite of hydrology tools available in the ArcGIS Spatial Analyst (ArcHydro Tools) Toolbox to hydrologically process the terrain data. Five sub-watersheds that make up Chester Creek were delineated and have a combined drainage area of 6.68 square miles.

Regional regression equations were used to calculate a rural peak discharge for a selected return period (i.e., storm event) and then a national urban regression equation was used to convert this to an urbanized peak discharge based on impervious areas. Impervious area for each sub-watershed was obtained by using the zonal statistics tool (ArcGIS) on the National Land Cover Dataset developed and maintained by the MRLC. Values for impervious area based on future development were obtained from the city of Duluth. The USGS regression equations require the use of 2-year, 2-hour TP-40 precipitation values. For Duluth, the current 2-year, 2-hour TP-40 precipitation is 1.5 inches. The calculated Chester Creek peak discharges at River Station 6787 range from 424 cfs for a 2-year storm to 1,530 cfs for a 100-year storm under current precipitation conditions (see Table 21). Velocities associated with storm intervals were calculated using the HEC-RAS hydraulic model. Peak discharge velocities range from 7.86 ft/s for a 2-year storm to 9.62 ft/s for a 100-year storm. These velocities are very high, which is indicative of the channelized flow that the ravine causes within Chester Creek.

Table 21. Chester Creek Current Land Use and Current Precipitation Peak Discharges and Velocities

Recurrence Interval	Peak Discharge (cfs)	Velocity (ft/s)
2-year	424	7.86
5-year	666	9.59
10-year	905	9.44
25-year	1,099	9.66
50-year	1,313	9.48
100-year	1,530	9.62

Source: Data calculated using USGS regression equation.

The peak discharges from the USGS regression equation were used as an input in HEC-RAS to determine flood depth grids from current storm events throughout the Chester Creek sub-watersheds.

4.4.2 Hazus Results

The city of Duluth's assessor database was used to populate the required Hazus attributes needed for analysis. Parcel centroids were assigned as proxies for all buildings within the Chester Creek watershed (see Figure 35). Each parcel received one centroid regardless of the number of buildings per parcel. One of the reasons that Hazus-estimated damages are low for Chester Creek is because many buildings do not lie within the watershed boundary (see Figure 35).

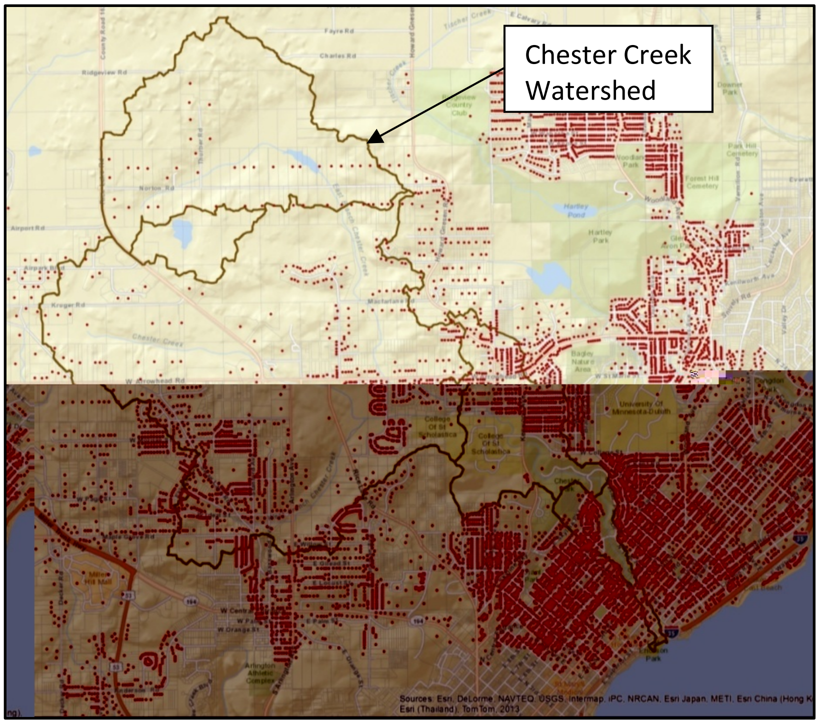


Figure 35. Chester Creek Parcel Centroids

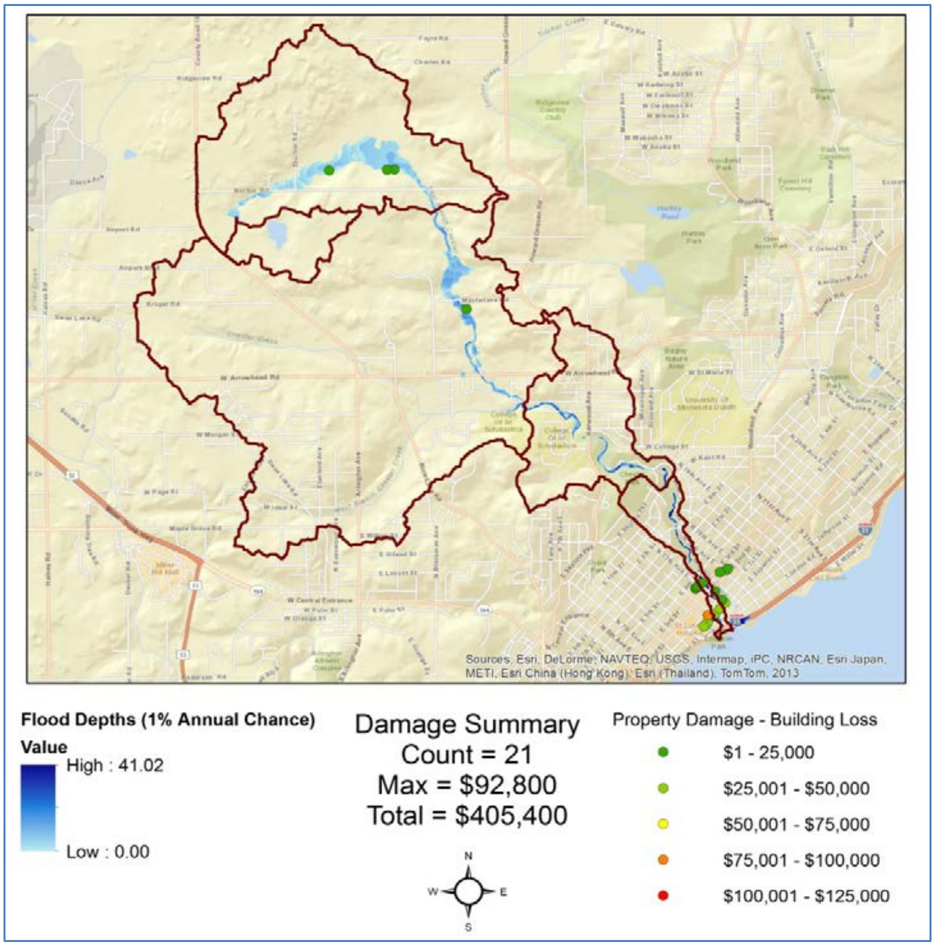
The flood damages to building structures from overbank flow for the current land use and current precipitation scenario in Chester Creek are summarized in Table 22.

Table 22. Chester Creek Current Land Use and Current Precipitation Flooding Damages

Recurrence Interval	Number of Buildings Damaged	Maximum Single Building Damage ($)	Total Damage ($)	Mean Damage Per Building ($)
2-year	10	$21,800	$108,900	$10,900
5-year	14	$92,800	$291,200	$20,800
10-year	15	$92,800	$309,300	$20,600
25-year	15	$92,800	$314,100	$20,900
50-year	18	$92,800	$373,000	$20,700
100-year	21	$92,800	$405,400	$19,300

Source: Hazus.

It was estimated that 21 buildings in Chester Creek would be damaged, totaling $405,400 in costs during the 100-year, 24-hour storm event under current precipitation conditions (see Figure 36). Flooding damages increased in Chester Creek as the storm recurrence interval increased. Because Hazus only assesses damages to buildings, the actual flooding damages are significantly higher than model estimates, due to the stream bank damage to which Chester Creek is prone along with other stormwater culverts and road infrastructure damage not accounted for with this model.



Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

Figure 36. Chester Creek Current Precipitation 100-year, 24-hour Storm Flooding Damages

4.5 Modeling Scenario 2: Future Land Use and Future Precipitation

The future year for this modeled scenario is assumed to be 2035. Future land use plans in the Chester Creek watershed include additional development in previously undeveloped areas. This means that the impervious area of the watershed will increase, which leads to an increase in stormwater runoff. In order to model the future land use scenario, the future land use impervious area was increased based on future zoning in consultation with the Duluth City Planning Department. The future precipitation was estimated based on data extrapolated from CREAT.

4.5.1 H&H Results

A USGS regression equation was used for the hydrology modeling to calculate the peak discharge of the sub-watersheds within Chester Creek. Regional regression equations were used to calculate a rural peak discharge for a selected return period (i.e., storm event) and then a national urban regression equation was used to convert this to an urbanized peak discharge based on impervious areas. The future 2-year, 2-hour precipitation was estimated based on an extrapolation from CREAT. The extrapolation estimated that the 2-year, 2-hour TP-40 precipitation would increase by approximately 8.5 percent in the year 2035. For Duluth, the estimated future (2035) 2-year, 2-hour TP-40 precipitation is 1.63 inches, which is an 8.5 percent increase from the current 2-year, 2-hour precipitation value of 1.5 inches.

Overall, peak discharges increased 13 to 28 percent compared to scenario 1. The calculated Chester Creek peak discharges for River Station 6787 range from 544 cfs for a 2-year storm to 1,735 cfs for a 100-year storm (see Table 23). Peak discharges in the future precipitation and future land use scenario increase from both an increase in precipitation and an increase in impervious area. An increase in peak discharges will usually cause an increase in runoff velocities, which is a known cause of stream bank failure. Velocities associated with storm intervals were calculated using the HEC-RAS hydraulic model. Peak discharge velocities range from 8.86 ft/s for a 2-year storm to 9.87 ft/s for a 100-year storm. It should be noted that the relationship between peak discharge and velocity is not linear and will vary depending on factors such as river geometry and geology.

Table 23. Chester Creek Future Land Use and Future Precipitation Peak Discharges and Velocities

Recurrence Interval	Peak Discharge (cfs)	Velocity (ft/s)	Percent Change from Current Peak Discharge (Scenario 1)	Percent Change from Current Peak Velocity (Scenario 1)
2-year	544	8.86	28	13
5-year	807	9.26	21	-3
10-year	1,066	9.84	18	4
25-year	1,263	9.55	15	-1
50-year	1,488	9.61	13	1
100-year	1,735	9.87	13	3

Source: Data calculated using USGS regression equation.

The peak discharges from the USGS regression equation were used as an input in HEC-RAS to determine flood depth grids from future storm events throughout the Chester Creek sub-watersheds.

4.5.2 Hazus Results

Hazus was used to estimate future flood damages to buildings within the Chester Creek watershed based on the flood depth grids developed through H&H modeling. The Hazus assumptions in modeling scenario 1 (current land use and current precipitation) are the same for modeling scenario 2 (future land use and future precipitation). Damages in Chester Creek were greater for the future land use and future precipitation scenario than the current land use and current precipitation scenario. The increase in damages between scenarios 1 and 2 is summarized in Table 24. The expected monetary value associated with these damage reductions over a 20-year period is estimated in the benefits analysis.

Table 24. Chester Creek Future Land Use and Future Precipitation Flooding Damages

Recurrence Interval	Number of Buildings Damaged	Maximum Single Building Damage ($)[a]	Total Damage for all Buildings ($)	Mean Damage Per Building ($)	Total Damage Percent Change (from Scenario 1)
2-year	13	$37,700	$194,900	$15,000	79%
5-year	15	$92,800	$306,900	$20,500	5%
10-year	16	$92,800	$318,200	$19,900	3%
25-year	17	$92,800	$364,400	$21,400	16%
50-year	18	$92,800	$378,100	$21,000	1%
100-year	22	$95,100	$419,900	$19,100	4%

Source: Hazus.

Table Notes:

a. Assessed values are in 2013 dollars.

It was estimated that 22 buildings in Chester Creek were damaged, totaling $419,900 in costs during the 100-year, 24-hour storm event under future (2035) precipitation conditions (see Figure 37).

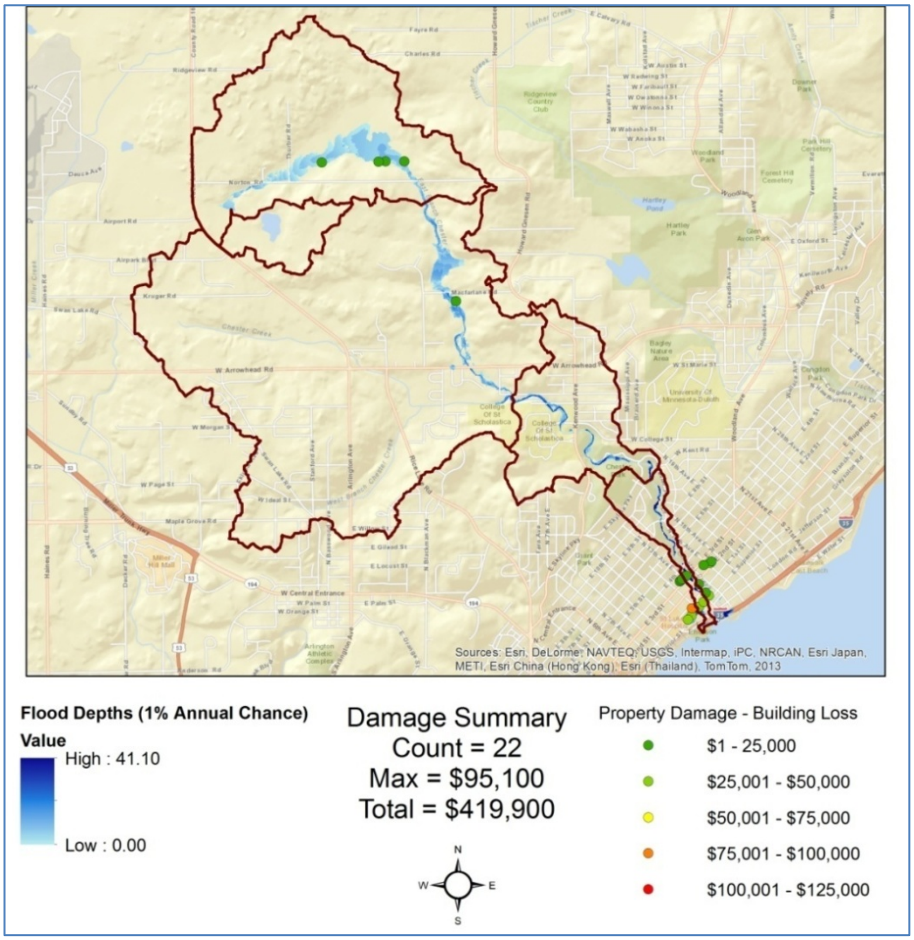


Figure 37. Chester Creek Future Precipitation 100-year, 24-hour Storm Flooding Damages

Most of the anticipated future development in the Chester Creek watershed is outside of the flooding zone where damages are incurred. Thus, flooding in the future precipitation and future land use scenario should impact no new structures. As mentioned previously, Hazus only models damages to buildings; it is anticipated that additional damages not summarized in Table 24 would be incurred in Chester Creek during storm events.

4.6 Modeling Scenario 3: Current Land Use and Current Precipitation with Flood Storage

The goal of scenario 3 is to look at how the community could reduce flooding damage under current conditions in Chester Creek if a 20 percent increase in flood storage was provided. A 20 percent flood storage value was used because its associated acre-feet value was considered an achievable goal within the Chester Creek watershed based on discussions with the community. In scenario 3, all of the land use and precipitation assumptions are the same as in scenario 1. The difference in this scenario is that it is assumed that peak discharges are reduced by 20 percent at River Station 6787 through the implementation of stormwater management and GI upstream. A 20 percent reduction in peak discharge correlates to an associated storage volume of runoff. This scenario looks at the flooding damage caused if the current conditions in Chester Creek remain the same, except for a 20 percent increase in flood storage.

Flood Storage Volume = (1,530 ft^3/sec - 1,224 ft^3/sec)(3 hours)(60 sec/min)(60 min/hr)(acre/43,560 ft^2) = 76 acre-feet. It was assumed that the peak flow is reduced by 20 percent for three hours. The three-hour reduction time was chosen based on engineering judgment and is somewhat arbitrary; however, it does provide an order of magnitude estimate of the storage volume needed for peak flow reduction.

4.6.1 H&H Results

The 100-year, 24-hour peak discharge at River Station 6787 in Chester Creek is 1,530 cfs under scenario 1. That flow was reduced by 20 percent to 1,224 cfs for the scenario 3 analysis. Reducing peak discharges by 20 percent results in a four-to-five percent decrease in velocity for all storm events (see Table 25). A 20 percent peak discharge reduction for scenario 3 is equal to 76 acre-feet of flood storage. This means that if the community wanted to reduce peak discharges by 20 percent during a 100-year, 24-hour storm event, 76 acre-feet of storage would need to be provided upstream of River Station 6787.

Reducing peak discharges and accounting for 76 acre-feet of storage changes the flood depth grids generated by HEC-RAS. HEC-RAS was re-run assuming that 76 acre-feet of storage was added, which resulted in depth grids for the Chester Creek sub-watersheds that represent flooding when storage is provided under current land use and precipitation conditions.

One limitation of one-dimensional hydraulic models (like HEC-RAS) is that they provide AVERAGE velocities. The increase in velocities seen in the Chester Creek analysis may be a result of such averaging. Higher flows likely have more, slow moving water in overbank areas than lower flows confined more to the channel; this may inaccurately skew averages.

Table 25. Chester Creek Peak Discharges and Velocities for Current Land Use and Current Precipitation with Flood Storage

Recurrence Interval	Peak Discharge (cfs)	Velocity (ft/s)	Percent Change from Current Peak Discharge (Scenario 1)	Percent Change from Current Velocity (Scenario 1)
2-year	339.4	7.24	-20%	-8%
5-year	532.5	8.78	-20%	-8%
10-year	723.7	8.99	-20%	-5%
25-year	879.3	9.40	-20%	-3%
50-year	1050.1	9.82	-20%	4%
100-year	1223.7	9.53	-20%	-1%

Source: Data calculated using USGS regression equation.

4.6.2 Hazus Results

Hazus was used to estimate flood damages to buildings within the Chester Creek watershed based on the flood depth grids developed through H&H modeling of the current land use and a current precipitation scenario with a 20 percent reduction in peak discharge flows (i.e., 76 acre-feet of storage). The Hazus assumptions in scenario 1 are the same for scenario 3.

Reducing the peak discharge with the implementation of green infrastructure reduces the flood losses. It was estimated that 13 buildings in Chester Creek were damaged totaling $286,600 in costs during the 100-year, 24-hour storm event under current precipitation conditions (see Figure 38).

Reducing the peak discharge by 20 percent at River Station 6787 resulted in a nine to 47 percent reduction in total building flood damages for various storm events (see Table 26). The same peak discharge reduction also resulted in 13 to 50 percent fewer buildings being damaged in a storm event (see Table 26). The expected monetary value associated with these damage reductions over a 20-year period is estimated in the benefits analysis (Section 4.10).

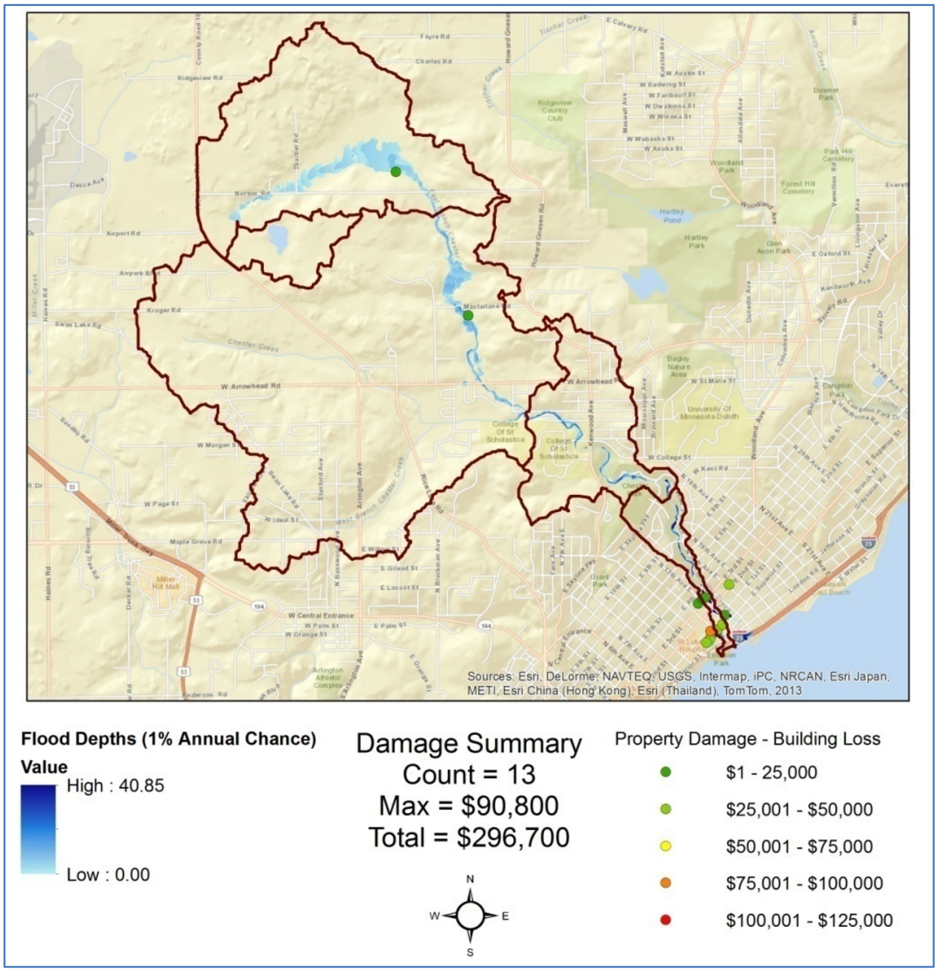


Figure 38. Chester Creek Current Land Use and Current Precipitation 100-year, 24-hour Storm Flooding Damages with Flood Storage

Table 26. Chester Creek Flooding Damages for Current Land Use and Current Precipitation with Flood Storage

Recurrence Interval	Number of Buildings Damaged	Maximum Single Building Damage ($)	Total Damage for all Buildings ($)	Mean Damage Per Building ($)	Number of Buildings Damaged Percent Change (from Scenario 1)	Total Damage Percent Change (from Scenario 1)
2-year	5	$21,800	$60,600	$12,100	-50%	-44%
5-year	10	$37,700	$154,800	$15,500	-29%	-47%
10-year	12	$92,800	$270,200	$22,500	-20%	-13%
25-year	13	$92,800	$286,600	$22,000	-13%	-9%
50-year	13	$92,800	$291,300	$22,400	-28%	-22%
100-year	13	$90,800	$296,700	$22,800	-38%	-27%

Source: Hazus.

4.7 Modeling Scenario 4: Future Land Use and Future Precipitation with Flood Storage

The goal of scenario 4 is to look at how the community could reduce flooding damage under future conditions if a 20 percent increase in flood storage was provided. In scenario 4, all of the land use and precipitation assumptions are the same as in scenario 2. The difference in this scenario is that it is assumed that peak discharges are reduced by 20 percent at River Station 6787 through the implementation of stormwater management and GI upstream. A 20 percent reduction in peak discharge correlates to an associated storage volume of runoff. This scenario looks at the flooding damage caused by the future conditions from scenario 2 coupled with a 20 percent increase in flood storage.

4.7.1 H&H Results

The 100-year, 24-hour peak discharge at River Station 6787 in Chester Creek is 1,735 cfs under scenario 2. That flow was reduced by 20 percent to 1,388 cfs for the scenario 4 analysis. Reducing peak discharges by 20 percent led to a range in velocity changes from an 11 percent decrease to a four percent increase (see Table 27). If the same amount of precipitation is falling within Chester Creek for scenarios 2 and 4, then the only way to reduce runoff volumes is to provide storage that prevents the precipitation from turning into runoff that travels to River Station 6787 within the creek. A 20 percent peak discharge reduction for scenario 4 is equal to 86 acre-feet of flood storage. This means that if the community wanted to reduce peak discharges by 20 percent during a 100-year, 24-hour storm event in 2035, 86 acre-feet of storage would need to be provided upstream of River Station 6787.

Flood Storage Volume = (1,735 ft^3/sec - 1,388 ft^3/sec)(3 hours)(60 sec/min)(60 min/hr)(acre/43,560 ft^2) = 86 acre-feet. It was assumed that the peak flow is reduced by 20 percent for three hours. The three-hour reduction time was chosen based on engineering judgment and is somewhat arbitrary; however, it does provide an order of magnitude estimate of the storage volume needed for peak flow reduction.

Reducing peak discharges and accounting for 86 acre-feet of flood storage changes the flood depth grids generated by HEC-RAS. HEC-RAS was re-run assuming the addition of 76 acre-feet of storage. This resulted in flood depth grids for the Chester Creek sub-watersheds that represent flooding when storage is provided under future land use and precipitation conditions.

Table 27. Chester Creek Peak Discharges and Velocities for Future Land Use and Future Precipitation with Flood Storage

Recurrence Interval	Peak Discharge (cfs)	Velocity (ft/s)	Percent Decrease from Future Peak Discharge (Scenario 2)	Percent Decrease from Future Velocity (Scenario 2)
2-year	435.4	7.92	-20%	-11%
5-year	645.8	9.59	-20%	4%
10-year	852.8	9.33	-20%	-5%
25-year	1010.2	9.66	-20%	1%
50-year	1190.5	9.57	-20%	0%
100-year	1388.1	9.56	-20%	-3%

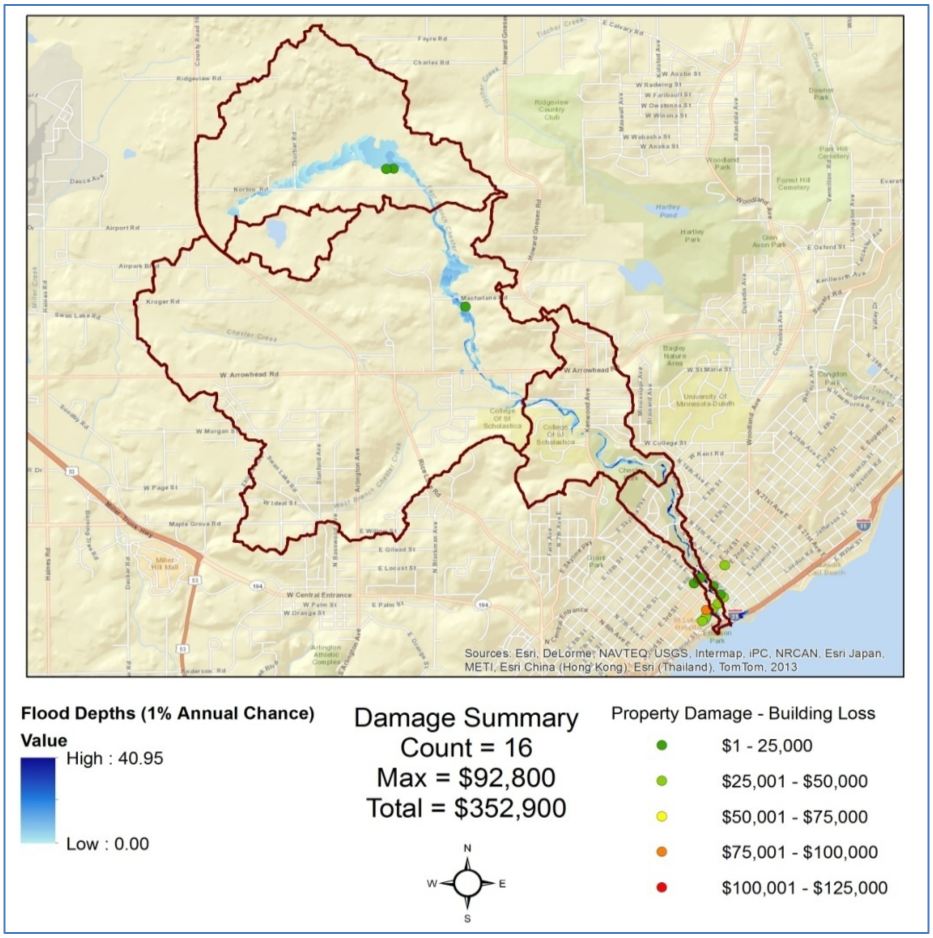
Source: Data calculated using USGS regression equation.

4.7.2 Hazus Results

Hazus was used to estimate flood damages to buildings within the Chester Creek watershed based on the flood depth grids developed through H&H modeling of the future land use and future precipitation scenario with a 20 percent reduction in peak discharge flows (i.e., 86 acre-feet of storage). The Hazus assumptions in scenario 2 are the same for scenario 4.

Reducing the peak discharge with the implementation of GI reduces the flood losses. It was estimated that 16 buildings in Chester Creek were damaged, totaling $352,900 in costs during the 100-year, 24-hour storm event under future precipitation conditions (see Figure 39).

Reducing the peak discharge by 20 percent at River Station 6787 resulted in a 10 to 55 percent reduction in building flood damage costs for various storm events (see Table 28). The same peak discharge reduction also resulted in 19 to 38 percent fewer buildings being damaged in a storm event (see Table 28).



Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

Figure 39. Chester Creek Future Land Use and Future Precipitation 100-year, 24-hour Storm Flooding Damages with Flood Storage

Table 28. Chester Creek Flooding Damages for Future Land Use and Future Precipitation with Flood Storage

Recurrence Interval	Number of Buildings Damaged	Maximum Single Building Damage ($)	Total Damage for all Buildings ($)	Mean Damage Per Building ($)	Number of Buildings Damaged Percent Change (from Scenario 2)	Total Damage Percent Change (from Scenario 2)
2-year	8	$21,800	$87,000	$10,900	-38%	-55%
5-year	12	$92,800	$268,400	$22,400	-20%	-13%
10-year	13	$92,800	$285,500	$22,200	-19%	-10%
25-year	13	$92,800	$289,000	$22,000	-24%	-21%
50-year	14	$92,800	$301,000	$21,500	-22%	-20%
100-year	16	$92,800	$352,900	$22,100	-27%	-16%

Source: Hazus.

4.8 Other Economic Benefits

Increased Recreational Use

Reduced flooding should increase the recreational use of areas that are impacted by flooding events. To evaluate the benefits from increased recreational use, several values must be identified: daily use values, number of annual visitors, and actual or hypothetical annual admission under various scenarios.

Day use values are based on work from Loomis (2005), who summarized the existing research and provided average daily use values for a wide-range of activities.[50,51] Average estimated use values were $63.37 per day. Alternatively, one could limit values to applicable site-specific activities. Then an unweighted average of the pertinent use values could be used to determine the average use value across all recreational attendees in Duluth’s Chester Creek Park (estimated to be $51.34).[52]

The estimated annual number of visitors is based on admission record data for recent years provided by the City of Duluth, Parks & Recreation Division. Attendance in 2011 was estimated to be 15,925 (the last year with full-data and no major storm event). Attendance in 2012, the year of the major storm, was 9,850. Since admission may grow over time, the admission growth rate is assumed to be equivalent to the city’s population growth rate (0.2 percent per year), resulting in an estimated attendance in 2013 of 15,989 without a major storm and 9,889 with a major storm.[53]

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[50] Loomis, John B, 2005. USDA Updated Outdoor Recreation Use Values on National Forests and Other Public Lands. USDA, Forest Service.

[51] We considered two other sources but these were either out of date or did not provide as much detail. Rosenberger, Randall S.; Loomis, John B., 2001. Benefit transfer of outdoor recreation use values: A technical document supporting the Forest Service Strategic Plan (2000 revision).

USDA, Forest Service. US Army Corps of Engineers, Economic Guidance Memorandum, 2012. Unit Day Values for Recreation for Fiscal Year 2012.

[52] If attendance by activity is known (or can be estimated), then the use of a weighted average of use values would improve the accuracy of the estimate.

[53] 2006 City of Duluth Comprehensive Plan.

Annual admission depends on the severity of storms occurring in the year; thus EAD calculations are used to predict admission.[54] For example, in year 1 admission numbers are estimated for each storm severity type and the EAD formula is used to estimate expected admission. Admission must be estimated for three other scenarios:

- Admission in 2035 <u>without</u> flood reduction.
- Admission in 2013 <u>with</u> flood reduction.
- Admission in 2035 <u>with</u> flood reduction.

These were estimated by adjusting the baseline admission numbers by the estimated change in peak discharge for each storm type and scenario, as estimated from the H&H model. Admission in years between 2013 and 2035 was estimated using linear interpolation.

Then the estimated annual change in admission, due to GI implementation, was multiplied by the average daily use value to estimate expected annual lost recreational benefits. Finally, the PV over 20 years was estimated to be $326,000, an annual benefit of $17,700.

Reduced Post Storm Land Restoration Costs

Implementing GI may reduce land restoration costs. These costs include stream bank erosion, washouts, and trail damage. There are land restoration costs associated with storms of all severity types; however, these costs are relatively minor for smaller storms. Therefore, only the reduction in land restoration costs associated with a 100-year storm were considered.[55]

Expected annual land restoration costs were estimated as the expected costs associated with a 100-year storm multiplied by the probability of a 100-year storm occurring (in the case of Chester Creek, the 100-year storm event was associated with peak discharge of 1,530 cfs in the vicinity of Chester Creek Park). The cost estimate was based on the costs of land restoration incurred as a result of the 2012 storm event, and provided by the Duluth Engineering Department (estimated land restoration costs totaled between $1.5 and $3.0 million). The low-end of the spectrum was used to estimate land restoration costs associated with a 100-year storm since the 2012 storm may have been larger than a traditional 100-year storm.

The probability of this magnitude of storm occurring is adjusted based on the estimated percent chance that a storm with peak discharge of 1,530 cfs will occur in a year under the four scenarios. For example, for the current land use and current precipitation scenario, the percent chance of a storm with 1,530 cfs of peak discharge occurring is one percent. Therefore, the expected annual cost is $15,000 (one percent of $1.5 million). Flood mitigation reduces the probability of a storm with peak discharge of 1,530 cfs occurring to 0.24 percent. Consequently, the expected annual costs are reduced to $3,610 (0.24*1.5 million). Increased precipitation or land use increases the probability to 1.84 percent and expected annual costs to $27,623. See Appendix D for additional numbers.

Over the 20-year period the PV attributed to reduced post storm land restoration costs is estimated to be $263,400 and the annualized benefit is $14,300.

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[54] Although admission is not a type of "damage," the EAD formula is applicable to estimating expected admission.
[55] These costs are also limited to 100-year storms due to data limitations. Future work utilizing this methodology may want to estimate the reduction in land restoration costs across all storm severity types using an EAD type calculation.

Reduced Storm Sewer Infrastructure Costs

Flooding causes wear and tear on the storm sewer infrastructure; thus implementing GI may reduce and/or increase the longevity of the stormwater system, deferring costs over time. Two types of stormwater infrastructure costs were calculated: 1) Operation & maintenance (O&M) costs and 2) Regular replacement costs.

There may be additional replacement costs associated with major storms that could be reduced or deferred with GI such as damages to roads, bridges, and sidewalks. However, due to data limitations, these were not considered in this analysis. Future analyses could incorporate these costs using the same methodology as the other storm sewer infrastructure costs considered.

O&M and regular replacement costs were generally available from the city of Duluth Engineering Department. These values are used to estimate costs for the current land use and current precipitation scenarios. Current O&M costs in the Chester watershed were estimated to be $50,000 per year. O&M costs for the city of Duluth were estimated to be $1.6 million and since the Chester watershed is approximately 1/16th of the city and half of O&M costs are considered fixed costs, we attributed 1/32nd of the cost to the Chester watershed (1.6M/32=0.05M). Regular replacement costs in the city of Duluth were estimated by the city of Duluth Engineering Department to be $1 million. We attributed 1/16th of this cost to the Chester Creek watershed, or $62,500.

Next, we need to estimate how these costs would change based on future land use, future precipitation, and adaptive GI (i.e., scenarios 2, 3, and 4). Costs for these scenarios used the baseline costs and the change in expected future peak discharge. The H&H model estimates the increase in peak discharge associated with increased land use and precipitation. The model also estimates the reduction in peak discharge associated with GI for both the current and future land use and precipitation scenarios. These estimated changes in peak discharge and EAD calculations were used to estimate the reduction in O&M and regular replacement costs for storm sewer infrastructure.

Over the 20-year period the PV attributed to reduced storm sewer infrastructure costs is estimated to be $158,600 and the annualized benefit is $8,600.

4.9 Flood Storage with GI

As was shown in the assessments in Sections 4.6 and 4.7, providing a 20 percent reduction in peak discharge through flood storage has a beneficial impact by reducing flood damages. A 20 percent reduction in peak discharge is equivalent to 76 acre-feet under current conditions and 86 acre-feet under future conditions (see Table 29).

Table 29. Chester Creek Storage Volumes for the 100-year, 24-hour Storm Event

Scenario	Percent Reduction in Peak Discharge	Storage Needed (acre-feet) to Achieve Percent Reduction in Runoff Volume
1. Current Land Use/ Current Precipitation	20%	76
2. Future Land Use/Future Precipitation	20%	86

Source: Data calculated using USGS regression equation.

Flood storage can be achieved in a variety of ways. It is recommended that flood storage be achieved throughout a watershed through the implementation of GI because in addition to managing stormwater, it provides aesthetic and ecological benefits. The type of GI implemented on a site depends on factors such as:

- Site hydrology (permeability, soil, slope, ground cover).
- Available open space.
- Community preference/acceptance.
- Presence of underground of obstructions such as utility lines.
- Presence of natural features such as public shade trees.
- Cost.

In order to achieve 76 to 86 acre-feet of storage, a variety of GI could be implemented on multiple sites. Lots of GI practices can be designed to have small-scale applications, which is advantageous because they can be implemented in some manner as a retrofit or as part of new construction on almost any property. There are multiple ways that a community can mix and match different types of flood storage options in order to achieve the end result of a certain number of acre-feet of storage. Each community will need to determine the best combination of practices and sites.

In the Chester Creek watershed, some specific GI opportunities were identified based on a review of GI strategies, a preliminary screening of those strategies suitable for Chester Creek watershed, and vetting with the community. Those opportunities include:

- Installing bioretention in the form of bioswales along the approximately 15 miles of unimproved roadway above the bluff (roads without curbs and drainage systems), as well as rain gardens as demonstration projects and for raising awareness throughout the community.
- Working with local industries to install blue roofs in the Kenwood neighborhood where there is more than 350,000 square feet of commercial roof top.
- Installing permeable pavement sidewalks along unimproved roadways as they are re-paved or replacing pervious sidewalks with impervious ones when they are replaced.
- Installing underground storage beneath parking lots, roadways, and other developed areas.
- Installing stormwater tree trenches along existing and new sidewalks as they are built.
- Installing stormwater retention ponds in open areas including the possibility of partnering with local college institutions (St. Scholastica and University of Minnesota, Duluth), which are embracing green practices and are optimally located in the watershed.
- Building an extended detention wetland in the upstream portions of the watershed and re-meandering a portion of the stream and associated floodplain.
- Preserving, maintaining, and re-establishing vegetation in the open space areas in the upstream portions of the watershed.

In addition to the flood storage options, installing in-stream velocity reduction practices such as root wads would greatly reduce stream scour and damage by decreasing the velocity of runoff as it flows through the creek below the bluff.

Cost is a large factor to consider when deciding what GI practices should be implemented on a site. In general, GI has economies of scale and can be sequenced over time, while other municipal work is occurring in the vicinity, to reduce marginal costs. Costs vary widely between geographic areas and are extremely site-specific. The project team performed a literature review of available GI costs nationwide (see Table 30) and looked at both capital and O&M costs per square foot of surface area and per cubic foot of water storage for each type of GI practice.

Table 30. Green Infrastructure Estimated Unit Costs

Green Infrastructure Practice	Capital Costs		Operations and Maintenance Costs	
	Capital Cost per Square Foot of Surface Area Installed ($/SF)[1,2]	Capital Cost per Cubic Foot of Flood Storage Provided ($/CF)[1,2]	Annual O&M Cost per Square Foot of Surface Area Installed ($/SF/year)[1,2]	Annual O&M Cost per Cubic Foot of Flood Storage Provided ($/CF/year)[1,2]
Bioretention/Bioswale	26.0	21.2	0.9	1.3
Blue Roofs	4.0	6.0	0.2	N/A[3]
Permeable Pavement (Sidewalk)	7.6	16.8	0.02	N/A
Underground Storage[4]	N/A	41.3	N/A	1.3
Stormwater Tree Trench[5]	7500	N/A	N/A	N/A
Retention Pond	1.0	2.9	0.1	0.0
Extended Detention Wetland	2.6	1.3	0.03	N/A

Table Notes:

1. All costs are in 2012 dollars.
2. Refer to Appendix C for a summary of sources for capital and O&M costs.
3. N/A indicates that costs were not available.
4. The cost per cubic foot of storage is anticipated to be lower. One case study used to find average costs had a significantly higher $/CF values, which greatly increased the overall average. The median cost for underground storage in 2012 dollars was $17.2/CF. Refer to Appendix C.
5. Tree trench cost is per unit rather than per SF.

Another challenge with GI costs is that each practice has vastly difference design components, which makes a comparison between two GI practices difficult. The project team focused on manipulating the costs to reflect a constant variable between practices. Cost per square foot of practice is the most common unit found in case studies; however, a 100 square foot bioretention area could provide vastly different amounts of flood storage depending on its designed depth. Additionally a 100 square foot bioretention area is not comparable in flood storage to 100 square feet of blue roof. The constant variable chosen in order to equalize all GI practices was cubic feet of runoff storage provided. Utilizing a cost per cubic foot of storage allowed the GI practices to be compared relative to each other.

Based on the team's research, the various types of GI practices could be organized by relative costs (see Table 31). Stormwater tree trenches were left out of this comparison because their costs are only available as a per unit cost and could not be compared to the surface area or storage area values used to compare the other GI practices. Additionally, some practices that did not have sufficient capital or O&M cost information were not able to be included in the comparison.

Table 31. Relative GI Costs

	Capital Cost per Square Foot of Surface Area Installed	Capital Cost per Cubic Foot of Flood Storage Provided	Annual O&M Cost per Square Foot of Surface Area Installed	Annual O&M Cost per Cubic Foot of Flood Storage Provided
Most Expensive	Bioretention	Underground Storage	Bioretention	Underground Storage
	Permeable Pavement	Bioretention	Blue Roof	Bioretention
	Blue Roof	Permeable Pavement	Retention Pond	Retention Pond
	Extended Detention Wetland	Blue Roof	Extended Detention Wetland	
	Retention Pond	Retention Pond	Permeable Pavement	
Least Expensive		Extended Detention Wetland		

The GI costs relative to one another are also shown in Figure 40 and Figure 41. In general bioretention, underground storage, and permeable pavement tend to be more expensive than blue roofs, extended detention wetlands, and retention ponds. When considering which GI practices to implement in large quantities, communities should cost the various options with regard to flood storage volumes. Communities should identify the feasible opportunities that could support local goals or demonstrate new effective techniques, and then choose options that provide the greatest desired return on investment. In order to maximize the cost-benefit of implementing GI, the community needs to choose how to mix and match various practices to achieve the total acre-feet of storage desired.

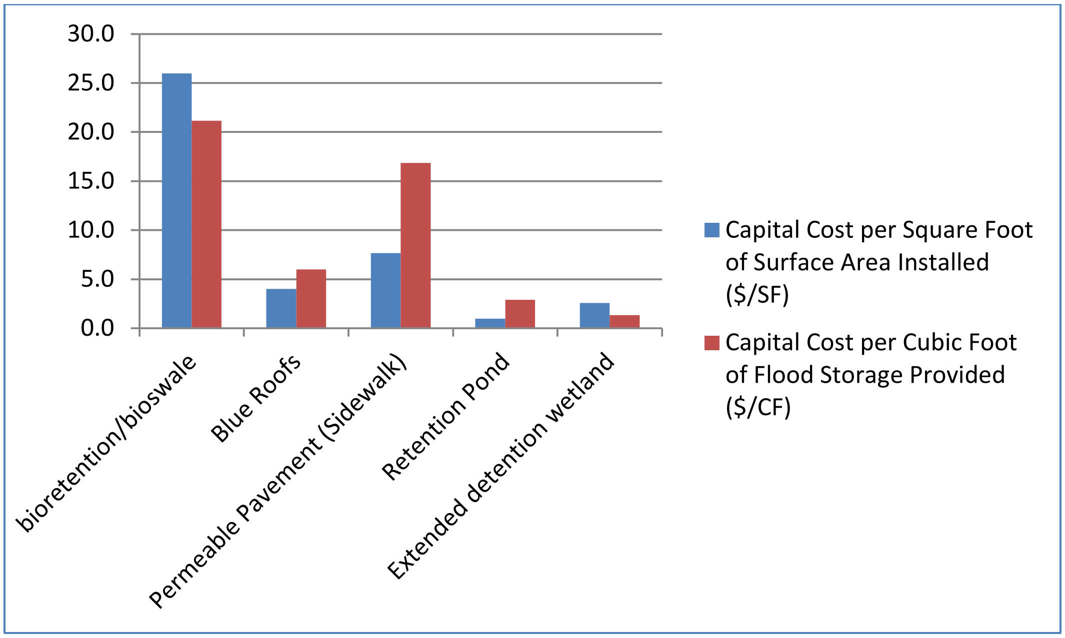

Figure 40. Relative GI Capital Costs

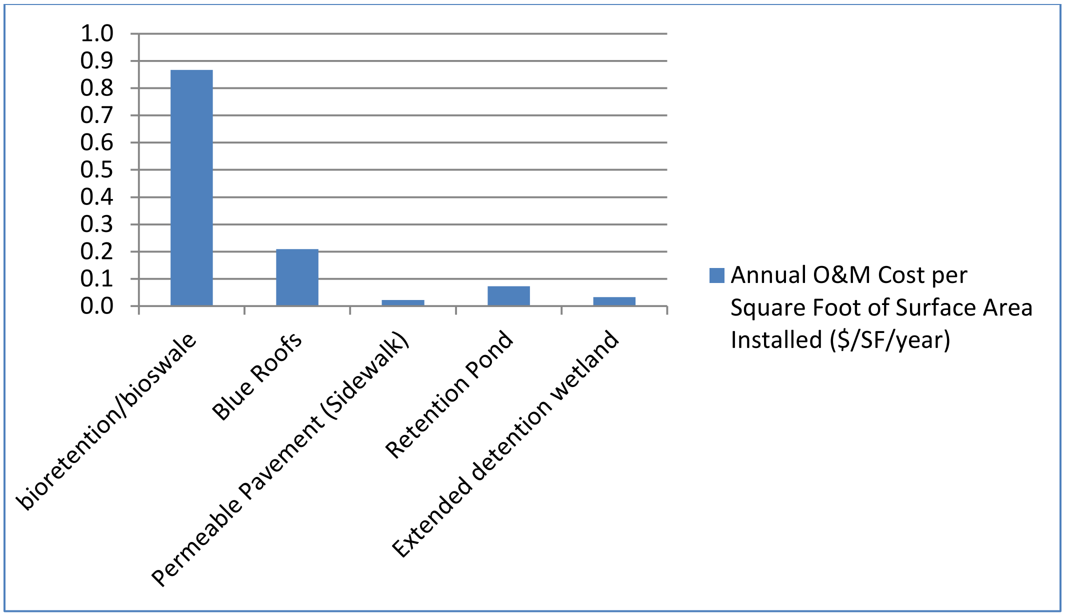

Figure 41. Relative GI O&M Costs

The cost of using GI to provide 31 acre-feet of storage in Toledo varies greatly depending on which practices were chosen. If 76 acre-feet of storage was provided with only extended detention wetlands (the least expensive GI practice) at $1.30/CF then the total implementation cost would be $4,303,728. If 76 acre-feet of storage was provided with only underground storage (the most expensive GI practice) at $41.30/CF then the total implementation cost would be $136,726,128. This is a very large range of estimated implementation costs but gives a starting point for communities to think about and encourages the implementation of GI practices that provide more storage for less capital costs.

To estimate the cost of GI, the community would multiply the unit cost of the type of GI times the volume of flood storage needed. If 76 acre-feet of storage was provided by constructing extended detention wetlands at a unit cost of $l.30 per cubic foot, it would cost: $1.30/ft ^{3} x 43,560 ft^2/acre x 76 acre-feet = roughly $4,300,000. If 76 acre-feet of storage was provided by installing underground storage at a unit cost of $4l.30 per cubic foot, it would cost: $41.30/ft ^{3} x 43,560 ft^2/acre x 76 acre-feet = roughly $136,700,000.

Duluth can begin estimating what it would cost to implement the different GI practices in identified locations where opportunities exist. For example, it is estimated that within the Kenwood area of Chester Creek there is at least 350,000 square feet of commercial roof space. The following steps could be taken to estimate the costs of blue roof implementation and the storage that could be obtained:

- 350,000 ft^2 of commercial rooftops in the Kenwood neighborhood.
- Assume 6” depth.
- Assume 75% of roofs could be retrofit with blue roofs.
- Total Storage = 350,000 ft^2*0.75*0.5 ft = **131,250 ft^3**
- 131,250 ft^3/43,560 ft^2/acre = **3.01 acre-feet**

- 131,250 ft^3*\$6/ft^3 = **\$787,500 → \$261,360 per acre-foot**

4.10 Summary of Benefit Analysis

The amount of reduced damages associated with flood mitigation strategies is represented as "benefits" (i.e., the difference between the economic impact of flooding without flood mitigation and those impacts with the implementation flood mitigation infrastructure). Monetized benefits include: reduced building damages, as well as increased recreational use; reduced flood damaged land restoration costs; and reduced storm sewer infrastructure costs. Other potential benefits, such as improved water quality, increased habitat, increased green space, and increased property values are important to consider, but were not able to be monetized in this study (Appendix B).

The total present value of all monetized benefits for 20 years is estimated to be \$1.63 million. This equates to roughly \$89,000 per year. When comparing these benefits to the expected costs, it is important to keep in mind that these benefits are an underestimate of the true benefits since many benefits, as well as some types of flood damages experience by Duluth, are not monetized. The majority of these benefits, 56.5 percent, are attributed to reduced structural damages. Increased recreational use results in \$326,000 in benefits (19.9 percent of the total). Reduced land restoration costs are estimated to be approximated \$263,000 over the 20-year period (16.1 percent of the total) and reduced storm sewer infrastructure replacement costs are \$122,000 (7.5 percent of the total). See Appendix D for annualized benefits.

The benefits calculated in this assessment are predicted to be much lower than those that would actually be provided for two main reasons: 1) additional benefits outside of avoided building damages were not monetized and 2) the benefit analysis ended at 20 years. Because non-monetized benefits such as increased habitat and improved water quality were not included in this study's assessment, the calculated benefits are likely to be greatly underestimated. Not all benefits are tangible and placing a value on an intangible benefit is difficult and subjective. It should be understood that the GI recommended in this study provides numerous benefits outside of the costs avoided from building damage. These non-monetized benefits should be acknowledged and considered by the community so that they are at least qualitatively incorporated into any cost-benefit analysis.

Additionally, many GI practices have benefits that continue beyond a 20-year time period. Ending a benefit analysis at 20 years assumes that at year 21 the benefit is zero dollars, which is not true for many GI practices. Because the economic benefit analysis in this study only went out 20 years, the overall benefits are further underestimated. Communities may want to consider longer benefit timelines in order to more accurately reflect the benefits provided by GI throughout its entire life cycle. If these benefits were extended to reflect a 50-year period, the PV would increase from \$1,634,932 to \$4,682,344 (a 186% increase).

If 76 acre-feet of storage was provided with only extended detention wetlands (the least expensive GI practice) at \$1.30/CF then the total implementation cost would be \$4,303,728.

4.11 Comparison of Benefits and Costs

Although we do not know the true benefits and costs associated with implementing GI in Duluth, the previous two sections have presented some analysis of benefits and costs, which can be compared to demonstrate the benefit-cost analysis the city may conduct. In Section 4.8 the cost of obtaining 76 acre-feet of storage with only the least expensive GI practice, extended detention wetlands, was calculated to be \$4,303,728. If a third of these costs were incurred in years two, four, and six of the analysis, then the PV of the cost would be $4,169,074 (Appendix D). This PV of cost occurs regardless of whether a 20-year of 50-year time horizon is considered since all costs are incurred in the first six years. In Section 4.9 the PV of benefits associated with reduced building damages over 20 years was estimated to be $1,634,932 and over 50 years as $4,682,344.

However, when comparing the above benefits and costs it is important to keep in mind that these values may not reflect the true benefits and costs to the city. Federal funds, state funds, or grants may also be available for green infrastructure construction, which would reduce the cost to the city. The true benefits are greater than the estimated benefits since many benefits are not monetized. Cost per unit of GI may vary significantly. The city needs to proceed from planning to design scale to calculate site-specific costs. As shown in Table 30, there is a wide range of costs depending on the type of GI implemented. To minimize costs the city can focus on cheaper solutions and sequence them to coincide with other capital projects or funding sources to reduce marginal costs. Additionally, the city must consider the lifespan of the GI project as an important factor in determining the timeframe over which to compare benefits and costs.

If benefits and costs over the 20-year time are compared, the costs ($4.17 million) exceed the calculated benefits ($1.63 million). However, when the time horizon is extended to 50 years the costs remain constant at $4.17 million but the benefits grow to $4.68 million. In this comparison benefits exceed costs, providing evidence in favor of implementing the GI project. This demonstrates the importance of determining the appropriate time horizon when calculating benefits and conducting a benefit-cost analysis.

4.12 Policy Options

In addition to the GI options noted above, it is clear from the analysis that future development above the bluff that increases impervious surface will increase runoff and worsen flooding. Although new development is not expected to encroach on the floodplain and thus is not projected to increase flood damages as calculated by Hazus, it will result in more impervious surface, increased runoff, and increased flooding by year 2035. Such development is likely to exacerbate flood damage below the bluff, requiring even more flood storage (or other mitigation measures) to offset additional runoff. Thus, Duluth should look very carefully at its land use planning and zoning above the bluff, and consider preserving as much open space there as possible. Likewise, preservation and enhancement (expansion) of headwater wetlands and floodplain areas above the bluff, especially strategically located expansion between developed areas and flood damage areas (edge of the bluff) should be considered in future open space and wetlands planning.

Solutions for reducing flooding impacts should focus on broader watershed-based solutions as well as site-specific development. Regarding the latter, the city should look carefully at the areas slated for "up-zoning" (zoning from less to more intensive use/impervious surface) and make informed decisions about the extent to which its stormwater ordinance can ensure no net increase in flooding under future precipitation conditions (2035) and for all storm events, taking into account both peak flooding and total flood volume. Ensuring that the ordinance requires no net increase should be a minimum performance standard. In areas where onsite options are limited, the city can consider "fee-in-lieu-of"[56] onsite stormwater improvements, where the fees are put into a fund for implementing some of the watershed-based solutions, such as open space preservation and protection and enhancement of wetlands as suggested above.

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[56] Also referred to as "Density Transfer Charge" (DTC). Some practitioners prefer the term DTC rather than "fee" because DTC is a substitute for TDRs.

One policy option to reduce building damage would be to implement “urban form" requirements (which help shape and structure the future of the city) for development in critical flood storage areas. Such requirements could dictate that structures have floodable first floors (e.g., parking garage, structures elevated on stilts, no critical utilities in basements).

Another option is to reconsider the up-zoning in locations that are critical to flood storage (e.g., above the bluff), and look for options to allow for that development to occur in areas that are not prone to flooding and that would not displace important flood storage capacity (e.g., in closer proximity to the downtown Duluth area). One way to do this, in addition to rezoning, is to enact a TDR from above the bluff to below the bluff. Employing a “density transfer charge” may make this mechanism easier to use. For more information about successful TDR program components and fee-in-lieu policy mechanisms, see Appendix E.

Finally, it was apparent to the team in conducting this analysis that flood storage alone is not likely to solve the problem because of the volume of storage that would be required to reduce exiting flooding as well as future projected flooding in lower Chester Creek watershed. Root wads or other devices designed to reduce velocity in the ravine should be seriously considered to avoid future damages to infrastructure and recreational uses.

4.13 Duluth Conclusions

The comparison of the current land use and current precipitation outputs to the future land use and future precipitation outputs indicate that precipitation is expected to increase along with flooding damages in the Chester Creek watershed. The following strategies are recommended to reduce flooding damages in the future:

- Reduce runoff volumes and increase flood storage above the bluff, particularly downstream of the commercial area with significant impervious areas:
    - Install blue roofs on commercial buildings.
    - Expand/restore floodplain areas.
    - Incorporate LID and other green infrastructure methods to reduce runoff and increase storage within commercial zone.
- Examine the impacts of future land use above the bluff to inform decisions on how to avoid worsening the flooding situation below the bluff.
- Reduce the velocity of flow within Chester Creek below the bluff by installing in-stream GI velocity-reduction techniques.
- Consider changes to stormwater standards to increase their effectiveness and require increased onsite retention.

As a next step and follow-on to this project, it is recommended that Duluth refine the watershed-level analysis from this study and begin to hone in on specific locations and GI practices that can be implemented in the Chester Creek and other watersheds. A more refined analysis would include developing site-specific concept plans, calculating stormwater runoff reductions, estimating the cost of implementation for chosen GI practices and developing a long-term implementation plan that takes advantage of economies of scale and leveraging other capital improvement projects.

Additional efforts could include the following:

- Create a green infrastructure task force that could spearhead the effort to implement flood-reduction strategies through requiring and promoting green infrastructure.
- Develop a public outreach campaign to inform citizens and local landowners/businesses about the benefits of green infrastructure.
- Provide more incentives for developers to incorporate green infrastructure into site plans.
- Plan and install a demonstration project that utilizes green infrastructure as a flood-reduction mechanism.
- Develop a green infrastructure inventory to track existing and planned GI practices/projects.

5.0 LESSONS LEARNED

All communities have unique challenges regarding topography, climate, geology, hydrology, and land use. Successful solutions to reduce flooding need to be tailored to individual community needs. The assessment of both watersheds in this study benefited from community involvement throughout the study. Because of the high level of engagement from community officials and local partners, the project team was able to get ideas, institutional knowledge, and data, as well as perform local "ground truthing," which is essential to ensure that the communities end up with a useful product.

5.1 Geophysical Environment Considerations

The Silver Creek watershed in Toledo, Ohio, drains into the Maumee River, the westernmost tributary of Lake Erie. The Silver Creek watershed in Toledo is densely developed and, thus, it is hampered by space limitations for siting GI and flood storage alternatives. Because the flood plain has been developed, the watershed is prone to flooding even during relatively low (2-year) intensity storm events. Other challenges to reducing runoff in Silver Creek include vast impervious surfaces, flat topography, and a high water table. The stormwater management controls needed to be tailored to an urban environment and geared towards re-development, retrofitting, and incentives that work within a predominantly impervious landscape. Furthermore, the solutions for Silver Creek must be strategically located to benefit the areas experiencing flooding (i.e., storage will not be effective if it is located downstream from the flood damage areas).

Unique topography is the primary challenge in Duluth's Chester Creek watershed, due to the existence of the so-called "bluff," a sharp drop in elevation from the relatively flat upper reaches of Chester Creek watershed to the shore of Lake Superior in downtown Duluth. Headwater wetlands and floodplains above the bluff provide critical flood storage. As the floodplains fill up and waters in the creeks rise, the tributaries turn into cascades of rushing water as they drain large volumes of increasingly high velocity floodwaters over the edge of the bluff and down into narrow, steep-sided ravines that empty into Lake Superior. Within Chester Creek, significant flood damage occurs due to bank failure and erosion caused by high-velocity flows and high-flood volumes as floodwaters cascade through the narrow ravine "below the bluff." Opportunities for flood storage exist "above the bluff"; however, there are relatively few opportunities within the area where flood storage is most critical– between the commercial zone (with high impervious surfaces) and the bluff precipice. Furthermore, to be effective in this watershed, flood mitigation strategies must include options that can reduce velocity in addition to options that reduce the volume of stormwater runoff.

5.2 Socio-economic Considerations

The costs associated with GI solutions are highly site-specific and therefore planners must be cognizant of the cost per acre-foot of storage gained or the cost per percent imperviousness reduced for each installation to gauge cost-effectiveness. Factors that can drive up the cost include the presence of underground utilities that have to be relocated or large trees that have to be removed or avoided.

Neighborhood acceptance of GI options is also very important, thus, pilot testing to show effectiveness is critical for widespread community support. In more urbanized environments, a combination of green and gray infrastructure is likely to be needed, and more extreme measures (e.g., buy-outs of parcels) and community-wide (as opposed to watershed-specific) land use and re-development plans are likely to be needed. For example, in Toledo, the project team discussed the idea of the city purchasing homes for sale in the most flood-prone areas and providing incentives to increase development density in more suitable locations. This would shift and concentrate future development into areas less prone to flooding. In this way, GI could be effectively integrated into a community-wide sustainability or climate adaptation plan.

5.3 Modeling and Data Considerations

H&H models are used to characterize the nature and magnitude of flooding. Modeling and analysis is only as good at the data that are available, so an important step in the process is assessing what data and models are currently available in the study area and making the best use of existing information. Models will need to be developed for study areas that do not have existing and working H&H models.

Although it was thought that an H&H model was available and previously built for each creek assessed in this study, it was discovered that the hydrologic model data available was not complete. HEC-HMS was initially used to import an existing HEC-1 hydrologic model of the study area; however, the model proved not to be a working model. An attempt was made to build a HEC-HMS model for the watersheds, but due to a lack of necessary data and parameter values for the watersheds, this was not possible. As a result, USGS regression equations were used in place of a hydrology model (see Section 2.3.2). In order to understand the level of effort required for a watershed assessment, it is recommended that prior to the selection of a watershed, the project team thoroughly research and confirm the availability and functionality of existing H&H models for the area, and whether they can be utilized as-is for a flooding analysis or not.

A number of limitations, which were a function of the data/modeling constraints, arose during H&H modeling during this study:

- Data availability.
- Differences between the published NHD flow lines and computed streamlines using a hydrologic-corrected digital elevation model (DEM).
- Lack of bathymetric data.
- Lack of bridge and culvert data.
- Lack of stream gage data for calibration.
- Lack of necessary watershed parameters to develop a HEC-HMS model as opposed to using USGS regression equations.

Despite these limitations, the project team was able to take advantage of the available information and data and adapt our method accordingly. We used GIS data and USGS regression equations to approximate future flooding hydrology and hydraulics. Although the model was too general to inform site-specific decisions, it was useful for watershed-wide planning scale evaluation, which can serve as a foundation for more specific design engineering at a smaller scale, as necessary.

The results of this analysis could be refined by developing a more advanced hydrologic model. While the hydrology regression equations were able to provide general planning targets (versus design values), and were adequate to meet the study goals, a more detailed spatial analysis would be beneficial to explore changes in development within the watersheds and sub-watershed-specific responses to various mitigation options. Improvements could be made to the HEC-RAS model with additional data and resources. The values from different climate and development scenarios in this study reflect limitations that exist in each of the land use and precipitation scenarios considered. It is important to keep in mind that a limited analysis may be adequate for the types and levels of decisions that need to be made at any particular point in a planning process, and there is no need to spend additional resources on more precise modeling if a general result gives an answer with enough certainty to guide decision making.

Challenges encountered during Hazus modeling were the result of unavailable or incomplete datasets and attributes that are needed by Hazus to develop the UDF datasets that represent individual buildings. Incomplete datasets or attributes require additional assumptions to be made, which increases the uncertainty in the modeled outputs. Examples of dataset and attribute assumptions that were made include:

- Structure cost.
- First floor elevation.
- Square footage.
- Foundation type.
- Number of stories.
- Year built.

In Duluth, the Hazus indicated that only minor damages result from overbank flooding. For example, Hazus showed a 100-year storm under current precipitation and land use conditions would result in overbank flood losses of $405,400 in Chester Creek. In June 2012, Duluth experienced an approximately 200-year storm that caused approximately $1.8 million in actual flooding damages within the Chester Creek watershed, including damages to stormwater culverts, stream banks, and near stream recreational uses. Additional economic analyses could be performed for Chester Creek in order to better estimate the true magnitude of all flood losses outside of what Hazus captures.

Interpretation of the findings of this present study should consider the scope of the models that have been used. Although sufficient to illustrate the nature and relative magnitude of the effects the planning scenarios have been considered (e.g. future climate, future land use scenarios), our analysis does not provide total loss values. The intent of this study was to provide a basis for assessing the relative effectiveness of different planning options in reducing flood damage.

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APPENDIX A
GREEN INFRASTRUCTURE OPTIONS

This Appendix provides overview fact sheets on the following green infrastructure practices focused on two aspects of stormwater management: improved water quality and increased storage.

- Bioretention/Green Street Practices.
- Rooftop Systems.
- Constructed Stormwater Wetlands.
- Infiltration Practices.
- Non-Structural Practices/Low Impact Development.
- Permeable/Porous/Pervious Pavement.
- Rainwater Harvesting/Storage.
- Stormwater Ponds: Wet and Dry.

Bioretention/Green Street Practices

Photo Source: www.epa.gov

Description: Bioretention systems use soils and landscape vegetation to capture, temporarily store, and treat stormwater runoff. They rely on vegetation in addition to filtration to promote pollutant uptake, attenuation, and evaporation. Bioretention practices are designed to accept runoff from lawns, roads, roofs, or parking lots. Existing green space can be excavated to provide storage, and native species are generally selected for landscaping.

Tree filters (bottom right) are compact, self-contained systems composed of soil media and vegetation. These systems are often seen in urban areas along sidewalks to collect and filter runoff from impervious surfaces. Stormwater planter-systems (top left) are designed to treat limited volumes of runoff. The planter boxes are filled with soil media and vegetation. These systems are easy to construct without the need for heavy excavation. Rain gardens (top right) are composed of flood-tolerant shrubs, flowers and grasses, and lack a complex soil matrix and underdrain. They collect and filter stormwater runoff, while adding aesthetic value, and are well-suited for installation in residential lots.

Approximate Costs:

The cost for bioretention systems is relatively moderate with rain gardens being the least costly system type. Implementation costs are typically in the range of $20-$30 per square foot for most bioretention systems. Tree planters generally have a higher cost due to installation and construction to accommodate underground storage.

System Types:

- Bioretention cells
- Tree filters
- Stormwater planters
- Rain gardens

Benefits:

- Maintain water balance and provide groundwater recharge.
- Promote pollutant uptake through vegetation.
- Utilize existing green space to serve a functional purpose while keeping aesthetic appeal.

Limitations:

- Not recommended for steep-sloped areas.
- Require regular maintenance.
- Must include design for overflows during heavy precipitation events.
- Not suitable for areas with minimal depth to bedrock.
- Sized for drainage areas less than ten acres.

Photo Source: Filterra

Rooftop Systems

System Types:

- Green roofs
  - Extensive green roofs
  - Intensive green roofs
- Blue roofs

Photo Source: Hazen and Sawyer

Approximate Costs:

Green roofs cost more than traditional roofs, ranging in cost from about $8 to $15 per square foot. Conventional asphalt shingles cost approximately $1 per square foot. However, green roofs have a long life, provide increased stormwater management, and decrease building energy consumption. Blue roofs are less costly – usually adding an additional $1-$5 to the cost of traditional roofs – and more versatile but lack the additional pollutant removal-benefits of green roofs.

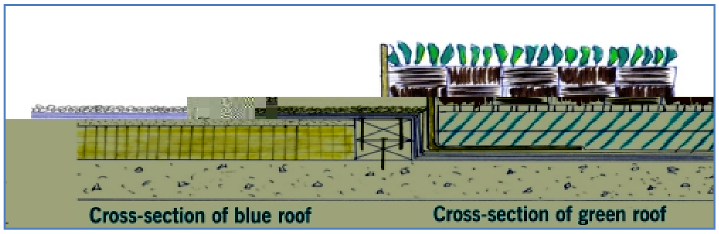

Photo Source: New York City Department of Environmental Protection

Description: Rooftop stormwater collection systems allow rooftop runoff to be slowed down and cleaned before it enters the existing drainage system.

Vegetated roof systems or "green roofs" capture rainfall using layers of vegetation and soil. Extensive green roofs are shallow, large-area, vegetated roof systems with low, drought-tolerant plants in less than 6" of soil. This type of green roof is vegetated and does not generally accommodate public access.

Intensive green roofs are deep, planter-type vegetated roof systems that are usually designed for public access (bottom right). These roofs hold more than 6" of soil and can support a diversity of vegetation including shrubs and small trees.

Photo Source: Arlington County, Virginia

Non-vegetated or "blue roof" practices (top left) are designed to detain water providing temporary storage and encouraging evaporation. These rooftop systems provide storage and detention to reduce peak flows and volume.

Benefits:

- Green and blue rooftops reduce stormwater peak flow and runoff volume.
- Green roofs provide additional pollutant removal through uptake and filtering.
- Can be used on many types of buildings.
- Intensive green roofs can be designed for public access.

Limitations:

- Do not provide groundwater recharge.
- Blue roofs require almost flat rooftops.
- Green roofs generally require slope less than 20%.
- Load restrictions can limit applicability for retrofits.

Photo Source: Prairie Ecosystems

Constructed Stormwater Wetlands

System Types:

- Shallow marsh systems
- Gravel wetlands

Photo Source: City of Cambridge, Massachusetts

Benefits:

- Improve water quality through pollutant removal.
- Reduce peak stormwater flow.
- Provide flood control for higher magnitude storms.
- Subsurface gravel wetlands provide year-round stormwater treatment in colder climates.

Limitations:

- Permitting and siting restrictions may apply.
- Require vegetation and habitat maintenance schedule.
- More costly than other green infrastructure practices.

Description: Constructed wetlands are man-made wetlands designed to filter and store stormwater runoff. Wetlands improve water quality by removing pollutants – naturally treating stormwater, reduce peak stormwater flows, serve as a flood control mechanism and reduce soil erosion.

Basin wetland systems (combined wet pond/shallow marsh) can treat the same volume of stormwater runoff as a shallow marsh system, but generally require less space and have higher pollutant removal efficiencies.

In gravel or horizontal wetlands (middle right) runoff flows through a rock filter with wetland plants at the surface. Pollutants are removed through biological activity on the surface of the rocks and pollutant uptake by the plants. Subsurface gravel wetlands are effective at providing year-round treatment in colder climate regions. However, gravel wetlands are not recommended for areas with high sediment runoff.

Photo Source: University of New Hampshire

Approximate Costs:

Installation cost data for wetlands are highly variable depending on size and other site complexities, such as permitting requirements and landscape variability. Some estimates indicate that installation costs for a one acre wetland could range from $40,000 to $100,000 depending on size and site considerations such as hauling and excavation costs, land acquisition, and vegetation purchases. Annual maintenance costs for stormwater wetlands are relatively low and estimated to range from approximately $780 - $1640 for a one acre wetland.

Infiltration Practices

System Types:

- Infiltration trenches
- Grass/vegetated swales
- Grass strips
- Biofilters/sand filters

Photo Source: Thomas Schueler, Chesapeake Stormwater Network

Approximate Costs: Costs for infiltration systems vary widely depending on site constraints such as inlet/outlet structure and design options. Infiltration basins (middle right) are typically the most cost effective. Infiltration trenches are usually in the range of $20-$30 per square foot. Underground chambers typically cost about twice as much as infiltration trenches.

Description: Infiltration practices, such as trenches, basins, swales, grass strips, biofilters, and sand filters provide significant water quality benefits. Infiltration trenches (top left) are shallow to deep excavations filled with stone to provide storage and infiltration into the sub-soil. These systems are practical for areas with limited space. Infiltration basins are excavated in fast-draining soils to create a temporary impoundment that allows for infiltration and groundwater recharge. Infiltration practices can reduce pollutant loading to receiving waters, provide effective peak flow control, and mitigate stream bank erosion.

The design of bioswales (bottom right) promotes the conveyance of storm water at a slower, controlled rate and acts as a filter medium removing pollutants and allowing stormwater infiltration. Bioswales are generally installed within or near paved areas such as parking lots or alongside roads and sidewalks, and trap silt and other pollutants that are normally carried in the runoff from impermeable surfaces.

Benefits:

- Improve stormwater quality.
- Provide temporary storage and help to reduce flooding during small storms.
- Promote infiltration and groundwater recharge.

Limitations:

- Generally require fast draining soils.
- Maintenance necessary to remove sediment buildup.
- Potential for groundwater contamination if not properly sited or pre-treated.
- Vegetated swales may provide limited treatment in severe winter weather.

Photo Source: New York City Department of Environmental Protection

Photo Source: U.S. Environmental Protection Agency

Non-Structural Practices/Low Impact Development

System Types:

- Open space preservation
- Encouragement of natural landscaping
- Reduction of impervious cover
- Street sweeping

Photo Source: New Brighton, Minnesota

Description: Non-structural green infrastructure practices refer to design strategies that limit and reduce the impacts of development/redevelopment on the local environment. Implementing these practices can reduce stormwater runoff volume and enhance the quality of runoff, limiting the need for additional and expensive structural systems.

Photo Source: U.S. Environmental Protection Agency

Benefits:

- Keeping open space land in preservation reduces impervious area and associated runoff while enhancing aesthetic value.
- Reverting to pre-development land cover and topography encourages infiltration and use of natural vegetated spillways.
- Limiting impervious area reduces the volume of runoff that must be managed.
- Street sweeping can reduce sediment and debris from clogging the stormwater system.

Photo Source: U.S. Environmental Protection Agency

Example Implementation Strategies

Open space preservation

- Require green space for development projects and define open space areas before performing site layout.

Encouragement of natural landscaping

- Keep or reconstruct pre-development vegetation and natural buffers and drainage ways to carry runoff.
- Minimize the amount of steep slopes.
- Reduce impervious cover
- Reduce parking lot area by minimizing space requirements and using landscape islands.
- Encourage shared parking, where appropriate.
- Use porous/permeable paving where feasible.
- Replace asphalt in school yards with open/green space.

Street sweeping

- Sweep entire street width as sediment builds close to the curb.
- Sweep monthly and immediately following snowmelt.

Permeable/Porous/Pervious Pavement

System Types:

- Permeable pavers
- Porous asphalt
- Pervious concrete
- Porous concrete

Photo Source: Boston Groundwater Trust

Benefits:

- Appropriate technique for many dense, already-developed urban areas – no additional land consumption.
- Improves water quality from underground media filtration.
- Provides groundwater recharge.
- Significantly reduces runoff quantity during storm events.
- Can potentially reduce the need for road salt use.

Limitations:

- Not applicable for steep-sloped landscapes.
- Requires pervious soils.
- Regular maintenance required to prevent clogging.

Description: Porous and permeable pavement allow for the absorption and infiltration of rainwater and snow melt into the native soil rather than allowing runoff to immediately enter the sewer system. Permeable paving is used to capture and temporarily store rainfall from smaller storm events – reducing runoff volume and improving water quality through soil filtration.

Permeable pavers (middle right) use impermeable blocks of brick, stone, or concrete in a grid with permeable sand or gravel in spaces between the blocks. This design allows rainfall to seep into the underlying soil. Porous asphalt (bottom and top left) looks similar to traditional roadway and parking lot pavement, but it is coarser with less stone to increase void space. Pervious concrete looks similar to traditional concrete pavement, but it is made with less aggregate that allows for a permeable surface.

Photo Source: U.S. Environmental Protection Agency

Photo Source: Horsley Witten Group, Inc.

Approximate Costs:

In general, porous pavement typically costs more than conventional pavement due to the sub-base which costs $3-$5 per square foot. The porous asphalt surface layer is similar in cost to conventional pavement. Pervious concrete and permeable pavers are more costly, typically about $9-$15 per square foot. The additional costs for paving can be partially offset by the need for approximately 80% less salting.

Rainwater Harvesting/Storage

System Types:

- Rain barrels
- Cisterns
- Underground tanks
- Flow-control valves

Photo Source: Invisible Structures

Benefits:

- Require minimal space and thus suited for urban residential, commercial, and/or industrial areas.
- Reduce consumer water remand.
- Reduce runoff volume to conventional stormwater facilities, especially with flow-control valves.

Limitations:

- No direct water quality improvement/pollutant removal benefits.
- Design should include an overflow mechanism to bypass larger storms.
- Without a flow-control valve, only retains a portion of the tank volume if not emptied prior to a storm.

Description: Rainwater harvesting/storage systems are designed to capture and store runoff for reuse or to reduce peak flows. Rain barrels (bottom left), above-ground cisterns, and underground tanks are closed containers that retain runoff for non-potable reuse purposes such as for landscaping and car washing.

A common approach to capturing roof runoff involves directing stormwater into a downspout and then into a 55-gallon rain barrel (bottom right). Larger underground tanks and cisterns (top left) ranging from 5,000 to 20,000 gallons can also provide additional storage; however costs for these types of installations can be significantly higher, depending on size, location, and siting configurations.

Manual or electronic flow-control valves can be used to control storage. In areas prone to flooding and combined sewer overflows, these valves can be used to harvest the peak flow and reduce downstream runoff.

Photo Source: Corridors of Opportunity

Photo Source: University of Rhode Island

Approximate Costs: The installed price ranges from $2-3 per gallon for small tanks to $1-2 per gallon for large tanks. Underground tanks cost more due to the cost of necessary excavation. Flow-control valves also present an additional cost.

Stormwater Ponds: Wet and Dry

Description:

A stormwater retention pond is one of the earliest prototypes of green infrastructure, and now considered a more traditional type of stormwater infrastructure because it has been integrated into gray infrastructure design.

Wet ponds (top left and bottom right) are constructed basins that have a semi-permanent pool of water throughout the year and at the very least during a wet season. Wet ponds contain an unrestricted spillway as the primary outlet, with a crest at the elevation of the permanent pool. The water stored in wet ponds is later displaced by new runoff.

Dry ponds (middle right) have no permanent pool and rely only upon extended detention storage for treatment volume. Dry ponds are more susceptible to sediment re-suspension and generally only useful for rate control.

Stormwater ponds offer temporary storage after storm events and also provide treatment for incoming stormwater by allowing pollutants and particles to settle and algae to take up nutrients.

Photo Source: U.S. Environmental Protection Agency

Benefits:

- Reduce peak stormwater flow.
- Improve water quality through pollutant removal.
- Provide runoff detention storage for channel protection and flood control.

Limitations:

- Require an adequate source of inflow to maintain pond surface and ecology.
- May increase downstream water temperature.
- Not suited for areas with a high water table, or near-surface bedrock.
- Should consider cold weather design modifications to avoid freezing and clogging of inlet and outlet pipes during winter months.
- May pose safety concerns.

Photo Source: City of Chelsea, Massachusetts

Approximate Costs: Costs for stormwater pond construction and maintenance are highly dependent on site specific conditions. The U.S. Environmental Protection Agency (EPA) estimates total costs for a 1-acre wet pond at around $45,000. This includes estimates for site design, construction, and permitting. Costs vary on a site-by-site basis depending on inlet/outlet structure, necessary debris and sediment removal, excavation and grading, and routine inspection and maintenance costs. Dry ponds costs are estimated to be slightly lower – approximately $41,000 for a 1-acre facility.

References

The fact sheets were adapted from the following resources:

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A Guide to Recognizing Its Economic, Environmental and Social Benefits."

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Horsley Witten Group, Inc., 2012. "Technical Support Document to Assist the City to Further Encourage and Promote the Use of Green Infrastructure." Report prepared for EPA Region 1.

Houle, K., 2006. "Winter Performance Assessment of Permeable Pavements: a comparative study of porous asphalt, pervious concrete and conventional asphalt in a northern climate." Thesis submitted to the University of New Hampshire in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering.

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Metropolitan Area Planning Council. Massachusetts Low Impact Development Toolkit. "Fact Sheet Number 2: Cisterns and Rain Barrels." Accessed May 2013.

Minnesota Pollution Control Agency. Minnesota Stormwater Manual. Accessed May 2013.

University of Minnesota Extension Service. 2006. "How Can I Create A Rain Garden?" http://www.extension.umn.edu/distribution/naturalresources/components/dd8241_4.pdf.

APPENDIX B
CO-BENEFITS OF IMPLEMENTATION STRATEGIES

Co-Benefits of Implementation Strategies

This appendix presents an overview of additional benefits that were not quantified in the report.[57] While the scope of this study did not allow for quantification of all benefits, the following provides a starting point for communities wishing to quantify additional benefits. When possible, the data potentially needed to quantify these additional benefits is identified and potential methodologies are discussed. Kousky et al. (2011) is a valuable source for cities wishing to consider these additional benefits and is referenced throughout this appendix.

The reason the following benefits were not quantified varies but in general was due to data limitations or resource constraints (e.g., time, budget). Additionally, some benefits could not be assessed because the benefits depend on the methods used to mitigate flood damage. For example, policies that create or preserve open space typically enhance the natural landscape, offering aesthetic benefits.

Additional benefits considered here include:

- Natural areas, open space, and improved wildlife habitat.
- Improved water quality.
- Higher property values.

Other potential benefits, that are not considered in detail here include:

- Reduced morbidity and mortality from floods.
- Reduced debris removal costs.
- Reduced agricultural damages.
- Reduced damages to vehicles.

Methodologies to value non-market benefits include:

- Willingness-to-pay and contingent valuation studies.
- Travel cost methodology.
- Benefit transfer methodology.
- Hedonic pricing models.

Natural areas, open space, and improved wildlife habitat

Natural assets have many benefits; however, these benefits are not quantified in this report because they can be more complex to assess than other types of assets. Most of these assets are public goods not allocated by market transactions, and therefore, are considered to have “non-market” values. They provide habitat for wildlife and cultural and aesthetic benefits that are not easily monetized. Such benefits, however, can be real and have significant sources of social welfare. They can be measured using non-market valuation techniques developed by environmental and natural resource economists. Natural areas provide both direct use value, indirect value, and non-use value.

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[57] Benefits monetized in this report include reduced structural damages in both Toledo and Duluth, along with several other benefits in Duluth, including: increased recreational use; reduced land restoration costs; and reduced storm sewer infrastructure costs.

Use-value is the benefit derived for people who directly use the space and is the easiest to quantify. Non-use benefits are the hardest to quantify and include benefits such as existence value. These types of benefits tend to be quantified with contingent valuation studies. Indirect use values include things such as reduced urban heat, smog, and ground-level ozone due to more trees and green space.

Expected improvements due to additional open space will depend on what, specifically, will be put on those lands (e.g., park, hiking trails, hunting grounds) and accessibility to the public. One methodology used to assess the value derived from increased use is the travel cost methodology. However, if the open space is close to urban areas the travel cost method may underestimate residents' willingness to pay to. Additionally, conducting travel cost surveys can be expensive. Another option is the benefit transfer methodology which uses information from other similar studies and applies the findings to the current situation. However, McConnell and Walls (2005) review open space studies and find that results vary widely by location, type of open space, and household type, and across studies. [58] Different methodologies and metrics make comparison across studies and benefits transfer to other areas complicated. It may be possible to use stated preference for aesthetic benefits and reduced congestion/open space.

Improved water quality

Green infrastructure may result in improvements in water quality which can result in increased fish catch rates, reduced sediment loads and corresponding decrease in frequency of dredging activities, and increases in beach visits.[59] Recreational or commercial fish catch data could be used to place a monetary value on improved fish catch rates (see Kousky et al. (2011)). Decrease in dredging costs could be estimated by multiplying the reduction in the number of times dredging is needed by the cost of dredging. A concern for this analysis is that in order to quantify the benefits one must establish a link between the policy considered and the anticipated biophysical impacts of those strategies. Kousky et al. (2011) determined that it may be necessary to construct a water quality model linked to outcomes that people value, like cost of drinking water, impacts on fish populations, visibility, recreation, beach closures, etc. One could then use a standard non-market valuation methods (for goods and services that are not traded on the market), which proxy willingness to pay in various ways. Kousky et al. (2011) has collected a lot of literature and data on non-market valuation of improved water quality.

Higher property values

The installation of green infrastructure can result in increased property values due to many of the benefits discussed above, such as improved aesthetics, increased recreational value, and improved water and air quality. The impact on property values will depend on proximity to the green infrastructure and the type of infrastructure. For example, open space may result in recreational value but permeable pavement would not.

Impacts of environmental changes on housing prices are generally assessed using hedonic price models. In property value hedonic price models a statistical regression is conducted where property values are estimated based on characteristics of the home and surrounding areas. By including in the model proximity to open land and green infrastructure, while controlling for house

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[58] Virginia McConnell and Margaret Walls. 2005. The Value Of Open Space: Evidence From Studies Of Nonmarket Benefits. Resources for the Future.

[59] Since the methodology for estimating recreational benefits, such as beach visits, is discussed in the main body of the report it will not be considered here.

specific-characteristics, one can estimate the impact on house prices. Hedonic price models capture willingness to pay for goods with market value through a revealed preference methodology. For an overview of the hedonic price method see Malpezzi (2002).[60]

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[60] Stephen Malpezzi. 2002. Hedonic Pricing Models: A Selective and Applied Review. The Center for Urban Land Economics Research, The University of Wisconsin.

APPENDIX C
GREEN INFRASTRUCTURE COSTS

Green Infrastructure Cost per Cubic Foot of Flood Storage Provided

Green Infrastructure Practice	Construction/O&M	Cost per CF of Storage	Cost per CF of Storage in 2012$	Source
bioretention/ bioswale	Construction	58	61.07	Assume cost in 2010$ biofiltration (drain tiles). Biofiltration cost w/ drain tiles should http://www.pca.state.mn.us/index.ph document.html?gid=1713
		16.76	16.76	Assume 2012$. $2.24/gallon of storage. MMSD Regional Green Infrastructure Plan. http://www.h2ocapture.com/PDF/final/MMSDGIP_Final.pdf
		10.7	11.27	Assume cost in 2010$ Range of costs based on 2005 Weiss et al source. Table 3 of document = 10.10-11.30 (median = 10.7) http://www.pca.state.mn.us/index.php/view-document.html?gid=17134
		6.4	9.16	Assume cost in 1997$ Brown, W., Schueler, T. The Economics of Stormwater BMPs in the MidAtlantic Region. 1997.
		5.3	7.58	Assume cost in 1997$ http://water.epa.gov/scitech/wastetech/guide/stormwater/upload/2006_10_31_guide_stormwater_usw_d.pdf
	Median	**10.7**	**11.3**	
	Average	**19.43126159**	**21.2**	
	Annual O&M	1.25	1.32	bioretention (no drain tiles) http://www.pca.state.mn.us/index.php/view-document.html?gid=17134
		5-7% of construction cost	5-7% of construction cost	Range of bioretention (no drain tiles) costs based on 1999 EPA source. Table 4 of document. http://www.pca.state.mn.us/index.php/view-document.html?gid=17134
		0.7-10.9% of construction cost	0.7-10.9% of construction cost	Range of costs based on 2005 Weiss et al source. Table 4 of document. http://www.pca.state.mn.us/index.php/view-document.html?gid=17134
	Median	**1.3**	**1.3**	
	Average	**1.3**	**1.3**	
Blue Roofs	Construction	6	6	Assume 2012$. Assume $1-5 per SF with a 6" depth. Median = $3/SF with 6" depth. --
	Median	**6.0**	**6.0**	
	Average	**6**	**6**	
Permeable Pavement (Sidewalk)	Construction	16	16.85	Cost in 2010$. http://www.pca.state.mn.us/index.p document.html?gid=17134
		17.50	17.50	Assume 2012$. $2.24/gallon of storage. MMSD Regional Green Infrastructure http://www.h2ocapture.
	Median	**16.0**	**16.8**	
	Average	**16.0**	**16.8**	

Green Infrastructure Cost per Cubic Foot of Flood Storage Provided

Green Infrastructure Practice	Construction/O&M	Cost per CF of Storage	Cost per CF of Storage in 2012$	Source
Underground Storage	Construction	213	224.3	Assume cost in 2010$. http://www.pca.state.mn.us/index.php/view-document.html?gid=17134
		16.31	16.6	Costs in 2011$. 37th Avenue North: Greenway Retrofit in Minneapolis, MN. Precast concrete box culvert sections (the largest being 18 feet wide and 10 feet high). Almost 1,400 lineal feet of underground box culverts 3.8 acre-feet of storage. Total project cost $2.7M
		13.55	18.1	Assume Costs in 2000$ Boneyard Creek, Champaign, IL CSP system http://water.epa.gov/scitech/wastetech/upload/2002_06_28_mtb_runoff.pdf
		6.24	8.3	Assume Costs in 2000$ Jordon Landing Mall, West Jordan, UT Aluminum system http://water.epa.gov/scitech/wastetech/upload/2002_06_28_mtb_runoff.pdf
		[illegible]	[illegible]	Assume Costs in 2000$ TF Green Airport, Providence, RI HDPE system http://water.epa.gov/scitech/wastetech/upload/2002_06_28_mtb_runoff.pdf
		12.89	17.2	Assume Costs in 2000$ Hauge Homestead State Park, Everett, WA HDPE system http://water.epa.gov/scitech/wastetech/upload/2002_06_28_mtb_runoff.pdf
		21.78	29.0	Assume Costs in 2000$ Homestead Village Hotel, Brookfield, WI Concrete system http://water.epa.gov/scitech/wastetech/upload/2002_06_28_mtb_runoff.pdf
		29.70	39.6	Assume Costs in 2000$ [illegible], Knoxville, TN Concrete box culvert system http://water.epa.gov/scitech/wastetech/upload/2002_06_28_mtb_runoff.pdf
		10.00	10.0	Costs range $3-$10. Chose $10 to be conservative. http://water.rutgers.edu/Projects/Sussex/4_GreenInfrastructurePlanningDesignandImplementationTrainingforDesignProfessionals.pdf
	Median	13.6	17.2	
	Average	36.7	41.3	
	Annual O&M	1.26	1.33	Assume cost in 2010$. http://www.pca.state.mn.us/index.php/view-document.html?gid=17134
	Median	1.3	1.3	
	Average	1.3	1.3	

[illegible]

	Green Infrastructure Practice	Construction/O&M	Cost per CF of Storage	Cost per CF of Storage in 2012$	Source
ect/09-	**Retention Pond**	Construction	7.97	7.97	Assume cost in 2012$. http://your.kingcounty.gov/dnrp/library/water-and-land/watersheds/green-duwamish/stormwater-retrofit-proje 13-2012-pmt-meeting/cost-assumptions-present-value.pdf
/2002_06_28_mtb_			1	1.41	Assume cost in 1998$ http://water.epa.gov/scitech/wastetech/upload, wetdtnpn.pdf
fbmps/index.cfm?ac			1.05	1.50	Assume cost in 1997$ http://cfpub.epa.gov/npdes/stormwater/menuo tion=factsheet_results&view=specific&bmp=68 $45,700 for a 1 acre-foot facility

es/stormwater/menuofbmps/index.cfm?ac
w=specific&bmp=68
t facility

	0.53	0.76	Assume cost in 1997$ http://cfpub.epa.gov/npde tion=factsheet_results&vie $232,000 for a 10 acre-foo
Median	**1.0**	**1.5**	
Average	**2.6**	**2.9**	
Annual O&M	0.03	0.03	Assum

e cost in 2012$.
http://your.kingcounty.gov/dnrp/library/water-and-
land/watersheds/green-duwamish/stormwater-retrofit-project/09-
13-2012-pmt-meeting/cost-assumptions-present-value.pdf

0.03	0.03	
0.03	0.03	
	1.05	Assume 2010$. Assumes 18" water quality treatment volume http://www.pca.state.mn.us/index.php/view-document.html?gid=17134
	1.32	

Median		
Average		
Construction	1	
	1.25	

Extended Detention Wetland

Cost in 2010$
Range of costs based on 1999 EPA source = 0.8-1.7. Median = 1.25.
[illegible]
document.html?gid=17134

1.30	1.37	Cost in 2010$ Range of costs based on 2005 Weiss et al source = 0.2-2.4. Median = 1.3. Table 3 of document. http://www.pca.state.mn.us/index.php/view-document.html?gid=17134
1.30	1.62	Assume cost in 2010$ 1 acre-foot = $57,000. $57,000/43,560 CF. http://www.sfwater.org/modules/showdocument.aspx?documentid=2778

/upload/

	0.93	1.32	Cost in 1997$ Range of Costs = 0.6-1.25. Median = 0.925. http://water.epa.gov/scitech/wastetech/guide/stormwater/ 2006_10_31_guide_stormwater_usw_d.pdf
Median	**1.3**	**1.3**	
Average	**1.2**	**1.3**	
Annual O&M	2% of construction cost	2% of construction cost	Cost based on 1999 EPA source. Table 4 of document. http://www.pca.state.mn.us/index.php/view-document.html?gid=17134

rce. Table 4 of
x.php/view-

4-14.2% of construction costs	4-14.2% of construction costs	Range of costs based on 2005 Weiss et al sou document. http://www.pca.state.mn.us/inde document.html?gid=17134

Green Infrastructure Cost Per Square Foot of Practice Area

		Cost Per SF		Cost Per SF (2012$)		
		Low	High	Low	High	Source
bioretention/bioswale	Construction	3	69	3.06	70.43	Cost in 2011$ http://www.stormh2o.com/SW/Articles/The_Costs_of_LID_20426.aspx

24 24 24.00 24.00 Assume 2012$.
MMSD Regional Green Infrastructure Plan.
http://www.h2ocapture.com/PDF/final/M
MSDGIP_Final.pdf
Assume cost in 2005$.
in 2012$.
en Presentation. Ask Nate what year these values are
20 30 20.00 30.00 Assume cost
Horsley-Witt
from?
30.55 30.55 30.55 30.55
st in 2012$.
.kingcounty.gov/dnrp/library/water-and-
sheds/green-duwamish/stormwater-retrofit-project/09-
13-2012-pmt-meeting/cost-assumptions-present-value.pdf
Assume co
http://you
land/water
Assume cost in 1999$
http://www.lid-stormwater.net/bio_costs.htm
10 40 13.78 55.12
35.98
Average 15.20 33.08 15.95
26.0
Median between Low and High 24.1
1.02 Assume cost in 2011$.
Annual O&M 1 1 1.02
2 1.22 1.22 1.22
Assume cost in 2012$.
http://your.kingcounty.gov/dnrp/library/water-and-land/watersheds/green-duwamish/stormwater-retrofit-project/09-13-2012-pmt-meeting/cost-assumptions-present-value.pdf
1.2
18 0.34 0.25 0.47
Assume cost in 1999$.
http://logan.cnt.org/calculator/pricing_sheet
U.S. Environmental Protection Agency. "Urban Stormwater Best Management Practices Study." EPA-821-R-99-012. August 1999.
0.1
0.80 0.85 0.83 0.90
w 0.8 0.9
Average
Median between Lo
and High
ofs Construction 1 5 1 5
Assume cost in 2012$.
Horsley-Witten Presentation. Ask Nate what year these values are from?
Assume cost in 2012$.
Blue Ro
.pdf
Average 3.00 5.00 3.00 5.00
Median between Low and High 4.0 4.0
cost in 2007$.
Assume blue roof cost is comparable to traditional
O&M.
20Annual%20Uniform%20Cost(1).pdf
roof cost for
media/Equiv%
0.14 0.19 0.20 0.27
cost in 1997$.
Assume blue roof cost is comparable to traditi
O&M. Schneider and Kennan reference.
http://www.roofingcenter.org/syncshow/uplo
20Annual%20Uniform%20Cost(1).pdf
onal roof cost for
aded_media/Equiv%
Average
0.2 0.2
Median between Low
and High

Green Infrastructure Cost Per Square Foot of Practice Area

		Cost Per SF		Cost Per SF (2012$)		
		Low	High	Low	High	Source
Permeable Pavement (Sidewalk)	Construction	5	10	6.38	12.76	Assume cost in 2002$ Interlocking concrete pavers http://www.lid-stormwater.net/permpaver_costs.htm
		10	10	10.00	10.00	Assume 2012$. MMSD Regional Green Infrastructure Plan. http://www.h2ocapture.com/PDF/final/MMSDGIP_Final.pdf
		2.5	5	2.77	5.54	Assume cost in 2007$. http://v3.mmsd.com/assetsclient/documents/wqi/2020Plan/SR_04.pdf

2012$.
county.gov/dnrp/library/water-and-
s/green-duwamish/stormwater-retrofit-project/09-
eeting/cost-assumptions-present-value.pdf
2005$.

Permeable pavers
http://www.cwp.org/...
avers.pdf
Low Impact Development in Puget Sound." March 2003.
http://logan.cnt.org/calculator/pricing_sheet
Assume cost in 2012$.
Porous pavement. Horsley-Witten presentation
Assume cost in 2008$.

5.00
12.80

3 | 5 | 3.00
3 | 12 | 3.53

s pavement.
/ww.crwa.org/projects/bmpfactsheets/crwa_permeable_p
t.pdf
2005$.
Asphalt.
ocwisconsin.org/wp-content/uploads/2012/10/TSR-2011-
ble-pavements.pdf
2005$.
s Concrete.
ocwisconsin.org/wp-content/uploads/2012/10/TSR-2011-
permeable-pavements.pdf
Costs in 2005$.
Pervious Concrete Pavers.
http://socwisconsin.org/wp-content/uploads/2012/10/TSR-2011-
permeable-pavements.pdf

0.5	1	0.59	1.18
2	7	2.35	8.23
5	10	5.88	11.76

2.59	8.43	Assume cost in 2001$. Porous concrete http://www.lid-stormwater.net/permpaver_costs.htm
5.5	9.8	
7.6		
0.00072	0.00072	Costs in 1989$. Based on $17/acre for vacuum cleaning => $0.00039/SF http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/Houle_JEE_July-2013.pdf
0.02	0.02	Assume cost in 2012$.

	2	6.5
Average	**5.0**	**8.8**
Median between Low and High	**6.9**	
Annual O&M	0.00039	0.00039
	0.02	0.02

http://your.kingcounty.gov/dnrp/library/water-and-land/watersheds/green-duwamish/stormwater-retrofit-project/09-13-2012-past-meeting/cost-assumptions-present-value.pdf

0.01	0.01	0.01	Assume cost in 2007$. http://v3.mmsd.com/assetsclient/documents/wqi/2020Plan/SR_04.pdf
0.02	0.02	0.02	Assume cost in 2012$.

(porous pavement, permeable pavers).
http://www.crwa.org/projects/bmpfactsheets/crwa_permeable_p
avers.pdf
Assume cost in 1991$.

verage	0.02	0.02	0.02	0.02
ledian between Low nd High	0.02		0.02	

Green Infrastructure Cost Per Square Foot of Practice Area

		Cost Per SF		Cost Per SF (2012$)		
		Low	High	Low	High	Source
Underground Storage	Construction	N/A	N/A	N/A	N/A	
	Annual O&M	N/A	N/A	N/A	N/A	
Stormwater Tree Trench	Construction	7500	7500	7500	7500	Assume costs in 2012$. $6,000 per unit and $1,500 per unit to install. htt p://www.lid-stormwater.net/treeboxfilter_costs.htm
	Average	**7500.0**	**7500.0**	**7500.0**	**7500.0**	
	Median between Low and High	**7500.0**		**7500.0**		
Retention Pond	Construction	1.03	1.03	1.03	1.03	Assume costs in 2012$. Based on $45,000 for 1-acre wet pond. Horsley-Witten Presentation (EPA)
		0.94	0.94	0.94	0.94	Assume costs in 2012$. Based on $41,000 for 1-acre dry pond. Horsley-Witten Presentation (EPA)
	Average	**1.0**	**1.0**	**1.0**	**1.0**	
	Median between Low and High	**1.0**		**1.0**		
	Annual O&M	0.07	0.07	0.07	0.07	Assume cost in 2012$. $7,830/ha/year for a wet pond. http:// [illegible] July-2013.pdf
	Average	**0.07**	**0.07**	**0.07**	**0.07**	
	Median between Low and High	**0.07**		**0.07**		
Extended Detention Wetland	Construction	0.86	2.15	0.86	2.15	Assume cost in 2012$. Horsley Witten presentation.
		4.48	4.48	4.96	4.96	Assume cost in 201 [illegible] Banklick Creek Regional Wetland in Sanitation District No. 1 of Northern Kentucky [illegible] 12.8 acres of wetland and approx. $2.5M [illegible]
		0.84	1.76	0.84	1.76	Assume 2012$. http:// [illegible] /projects/bmpfactsheets/cwp_stormwater_wetlands.pdf
	Average	[illegible]	[illegible]	[illegible]	[illegible]	
	Median between Low and High	**2.4**		**2.6**		
	Annual O&M	[illegible]	0.04	0.02	0.04	Assume cost in 2012$. [illegible] wetlands.pdf
	Average	**0.02**	**0.04**	**0.02**	**0.04**	
	Median between Low and High	**0.03**		**0.03**		

APPENDIX D
PRESENT VALUE AND ANNUALIZED BENEFITS AND COSTS TABLES

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Data Sources Used in the Economic Benefit Analysis

Benefit Type	**Estimate**	**Source**
Duluth & Toledo		
Reduced structural damage	Varies	HAZUZ output
Duluth Only		
Recreational Use		
Daily use values	$63.37 per visit	Loomis (2005) [a]
Attendance in 2011 and 2012	15,925 and 9,850	Duluth Parks & Recreation Division [a]
Reduced land restoration costs		
Land restoration costs incurred in 2012	$1.5 million	Duluth Engineering Department [a]
Reduced storm sewer infrastructure costs		
Current O&M costs	$50,000	Duluth Engineering Department [a]
Regular replacement costs	$1 million	Duluth Engineering Department [a]

[a] Involves assumptions made by ERG.

Avoided Damages and Present Value of Benefits in Toledo over 20 Years [a]

Year #	Year [b]	HAZUS
1	2013	$0
2	2014	$0
3	2015	$40,823
4	2016	$41,025
5	2017	$41,227
6	2018	$41,428
7	2019	$41,630
8	2020	$41,832
9	2021	$42,034
10	2022	$42,236
11	2023	$42,438
12	2024	$42,640
13	2025	$42,842
14	2026	$43,044
15	2027	$43,245
16	2028	$43,447
17	2029	$43,649
18	2030	$43,851
19	2031	$44,053
20	2032	$44,255
Present Value [c]		**$ 698,539**
Annualized		**$ 37,935**

Table Notes:

[a] This table is limited to benefits that can be quantified and thus is a lower-bound of the true benefits of green infrastructure.

[b] Benefits begin in 2015 because green infrastructure is estimated to be implemented by 2015.

[c] Calculation of the present value uses a discount rate of 0.8 percent.

Avoided Damages and Present Value of Benefits in Duluth over 20 Years [a]

Year #	Year [b]	HAZUS	Chester Creek Park			Total
			Recreational Use	Land Restoration	Storm Sewer Infrastructure	
1	2013	$0	$0	$0	$0	$0
2	2014	$0	$0	$0	$0	$0
3	2015	$53,933	$19,515	$12,292	$1,446	$87,185
4	2016	$54,201	$19,554	$12,742	$2,169	$88,666
5	2017	$54,470	$19,593	$13,193	$2,892	$90,147
6	2018	$54,738	$19,632	$13,644	$3,615	$91,629
7	2019	$55,007	$19,671	$14,094	$4,338	$93,110
8	2020	$55,276	$19,710	$14,545	$5,061	$94,592
9	2021	$55,544	$19,749	$14,996	$5,784	$96,073
10	2022	$55,813	$19,789	$15,447	$6,507	$97,555
11	2023	$56,082	$19,828	$15,897	$7,230	$99,037
12	2024	$56,350	$19,868	$16,348	$7,953	$100,518
13	2025	$56,619	$19,907	$16,799	$8,676	$102,000
14	2026	$56,888	$19,947	$17,249	$9,399	$103,482
15	2027	$57,156	$19,987	$17,700	$10,122	$104,964
16	2028	$57,425	$20,026	$18,151	$10,844	$106,447
17	2029	$57,693	$20,066	$18,602	$11,567	$107,929
18	2030	$57,962	$20,106	$19,052	$12,290	$109,411
19	2031	$58,231	$20,146	$19,503	$13,013	$110,894
20	2032	$58,499	$20,187	$19,954	$13,736	$112,376
Present Value [c]						**$ 1,634,932**
Annualized						**$ 88,786**

Table Notes:

[a] This table is limited to benefits that can be quantified and thus is a lower-bound of the true benefits of green infrastructure.

[b] Benefits begin in 2015 because green infrastructure is estimated to be implemented by 2015.

[c] Calculation of the present value uses a discount rate of 0.8 percent.

Structural Damage in Toledo: Annual Damages and Avoided Damages due to Green Infrastructure, 2013-2035

Year #	Year	Annual Damages			Avoided Damages	
		Without GI	With GI (Instant)	With GI (Delay)	With GI (Instant)	With GI (Delay)
1	2013	$108,199	$67,780	$108,199	$40,419	$0
2	2014	$108,862	$68,241	$108,862	$40,621	$0
3	2015	$109,526	$68,703	$68,703	$40,823	$40,823
4	2016	$110,189	$69,165	$69,165	$41,025	$41,025
5	2017	$110,853	$69,627	$69,627	$41,227	$41,227
6	2018	$111,517	$70,088	$70,088	$41,428	$41,428
7	2019	$112,180	$70,550	$70,550	$41,630	$41,630
8	2020	$112,844	$71,012	$71,012	$41,832	$41,832
9	2021	$113,508	$71,474	$71,474	$42,034	$42,034
10	2022	$114,171	$71,935	$71,935	$42,236	$42,236
11	2023	$114,835	$72,397	$72,397	$42,438	$42,438
12	2024	$115,499	$72,859	$72,859	$42,640	$42,640
13	2025	$116,162	$73,321	$73,321	$42,842	$42,842
14	2026	$116,826	$73,782	$73,782	$43,044	$43,044
15	2027	$117,489	$74,244	$74,244	$43,245	$43,245
16	2028	$118,153	$74,706	$74,706	$43,447	$43,447
17	2029	$118,817	$75,168	$75,168	$43,649	$43,649
18	2030	$119,480	$75,629	$75,629	$43,851	$43,851
19	2031	$120,144	$76,091	$76,091	$44,053	$44,053
20	2032	$120,808	$76,553	$76,553	$44,255	$44,255
21	2033	$121,471	$77,015	$77,015	$44,457	$44,457
22	2034	$122,135	$77,476	$77,476	$44,659	$44,659
23	2035	$122,799	$77,938	$77,938	$44,861	$44,861
Present Value (20 years)					**$778,616**	**$698,539**
Annualized					**$42,283**	**$37,935**

Structural Damage in Duluth: Annual Damages and Avoided Damages due to Green Infrastructure, 2013-2035

Year #	Year	Annual Damages			Avoided Damages	
		Without GI	With GI (Instant)	With GI (Delay)	With GI (Instant)	With GI (Delay)
1	2013	$151,242	$97,846	$151,242	$53,395	$0
2	2014	$153,094	$99,430	$153,094	$53,664	$0
3	2015	$154,946	$101,014	$101,014	$53,933	$53,933
4	2016	$156,799	$102,597	$102,597	$54,201	$54,201
5	2017	$158,651	$104,181	$104,181	$54,470	$54,470
6	2018	$160,503	$105,765	$105,765	$54,738	$54,738
7	2019	$162,356	$107,349	$107,349	$55,007	$55,007
8	2020	$164,208	$108,932	$108,932	$55,276	$55,276
9	2021	$166,061	$110,516	$110,516	$55,544	$55,544
10	2022	$167,913	$112,100	$112,100	$55,813	$55,813
11	2023	$169,765	$113,684	$113,684	$56,082	$56,082
12	2024	$171,618	$115,267	$115,267	$56,350	$56,350
13	2025	$173,470	$116,851	$116,851	$56,619	$56,619
14	2026	$175,322	$118,435	$118,435	$56,888	$56,888
15	2027	$177,175	$120,019	$120,019	$57,156	$57,156
16	2028	$179,027	$121,602	$121,602	$57,425	$57,425
17	2029	$180,880	$123,186	$123,186	$57,693	$57,693
18	2030	$182,732	$124,770	$124,770	$57,962	$57,962
19	2031	$184,584	$126,354	$126,354	$58,231	$58,231
20	2032	$186,437	$127,937	$127,937	$58,499	$58,499
21	2033	$188,289	$129,521	$129,521	$58,768	$58,768
22	2034	$190,141	$131,105	$131,105	$59,037	$59,037
23	2035	$191,994	$132,689	$132,689	$59,305	$59,305
Present Value (20 years)					**$1,028,914**	**$923,127**
Annualized					**$55,876**	**$50,131**

Average Consumer Surplus Values per Person per Day by Activity

Activity	Mean	Error	Limit to Activities Occurring [b]	
	2012 Dollars [a]		Indicator	Day Values
Backpacking	63.32	11.29	1	63.32
Birdwatching	35.98	10.15	1	35.98
Camping	45.20	7.01	1	45.20
Cross-country skiing	38.14	4.14	1	38.14
Downhill skiing	40.70	10.31	1	40.70
Fishing	57.32	5.85	1	57.32
Floatboating/rafting/canoeing	122.65	11.62	.	
General recreation	42.66	11.62	1	42.66
Going to the beach	47.92	11.62	1	47.92
Hiking	37.48	11.62	1	37.48
Horseback riding	22.02	0.00	1	22.02
Hunting	57.03	2.67	1	57.03
Motorboating	56.24	9.03	.	
Mountain biking	89.67	14.72	1	89.67
Off-road vehicle driving	27.86	4.80	.	
Other recreation	59.19	14.06	1	59.19
Picnicking	50.39	12.99	1	50.39
Pleasure driving	71.99	22.90	1	71.99
Rock climbing	68.38	8.34	1	68.38
Scuba diving	39.33	13.62	.	
Sightseeing	44.78	10.70	1	44.78
Snorkeling	36.84	18.67	.	
Snowmobiling	44.11	16.09	.	
Swimming	51.87	7.46	1	51.87
Visiting environmental education centers	7.30	0.00	.	
Visiting arboretums	16.46	0.00	.	
Visiting aquariums	34.41	0.00	.	
Waterskiing	59.58	15.46	.	
Wildlife viewing	51.49	3.21	1	51.49
Windsurfing	480.66	0.00	.	
Average	**63.37**			**51.34**

Source: Loomis, John B, 2005. USDA Updated Outdoor Recreation Use Values on National Forests and Other Public Lands. USDA, Forest Service.

[a] Loomis provides estimates for 2004; estimates in 2012 dollars are calculated by ERG.

[b] ERG estimates based on data issued by the City of Duluth, Parks & Recreation Division and knowledge about the park.

Chester Park Land Restoration Costs due to 100-Year Storm

Scenario	Percent Chance [a]	Costs if Occurs [b]	Expected Costs
Current land use/current precipitation	1.00%	$1,500,000	$15,000
Future land use/future precipitation	1.84%		$27,623
GI land use/current precipitation	0.24%		$3,610
GI land use/future precipitation	0.51%		$7,669

[a] Percent chance that a storm will occur in a year with peak discharge of 1,530 cfs and cause damage to Chester Creek

[b] $1.5 million is the lower-end of the estimated land restoration costs for Chester Park from the last major storm in Duluth.

Average Annual Land Restoration Costs in Chester Park due to 100-Year Storm

Year #	Year	Annual Facility Costs			Avoided Damages	
		Without GI	With GI (Instant)	With GI (Delay)	Instant	Delay
1	2013	$15,000	$3,610	$15,000	$11,390	$0
2	2014	$15,664	$3,824	$15,664	$11,841	$0
3	2015	$16,329	$4,037	$4,037	$12,292	$12,292
4	2016	$16,993	$4,251	$4,251	$12,742	$12,742
5	2017	$17,657	$4,464	$4,464	$13,193	$13,193
6	2018	$18,322	$4,678	$4,678	$13,644	$13,644
7	2019	$18,986	$4,892	$4,892	$14,094	$14,094
8	2020	$19,651	$5,105	$5,105	$14,545	$14,545
9	2021	$20,315	$5,319	$5,319	$14,996	$14,996
10	2022	$20,979	$5,533	$5,533	$15,447	$15,447
11	2023	$21,644	$5,746	$5,746	$15,897	$15,897
12	2024	$22,308	$5,960	$5,960	$16,348	$16,348
13	2025	$22,972	$6,174	$6,174	$16,799	$16,799
14	2026	$23,637	$6,387	$6,387	$17,249	$17,249
15	2027	$24,301	$6,601	$6,601	$17,700	$17,700
16	2028	$24,965	$6,815	$6,815	$18,151	$18,151
17	2029	$25,630	$7,028	$7,028	$18,602	$18,602
18	2030	$26,294	$7,242	$7,242	$19,052	$19,052
19	2031	$26,959	$7,456	$7,456	$19,503	$19,503
20	2032	$27,623	$7,669	$7,669	$19,954	$19,954
Present Value					**$ 286,388**	**$ 263,435**
Annualized					**$ 15,553**	**$ 14,306**

Storm Sewer Infrastructure: Replacement and O&M Costs in Chester Watershed

Year #	Year	Baseline			GI			Avoided Damages	
		O&M	Regular Replacement Costs	Total	O&M	Regular Replacement Costs	Total	Instant	Delay
1	2013	$50,000	$62,500	$112,500	$50,000	$62,500	$112,500	$0	$0
2	2014	$50,286	$62,857	$113,143	$49,964	$62,456	$112,420	$723	$0
3	2015	$50,572	$63,214	$113,786	$49,929	$62,411	$112,340	$1,446	$1,446
4	2016	$50,857	$63,572	$114,429	$49,893	$62,367	$112,260	$2,169	$2,169
5	2017	$51,143	$63,929	$115,072	$49,858	$62,322	$112,180	$2,892	$2,892
6	2018	$51,429	$64,286	$115,715	$49,822	$62,278	$112,100	$3,615	$3,615
7	2019	$51,715	$64,643	$116,358	$49,787	$62,233	$112,020	$4,338	$4,338
8	2020	$52,000	$65,000	$117,001	$49,751	$62,189	$111,940	$5,061	$5,061
9	2021	$52,286	$65,358	$117,644	$49,715	$62,144	$111,860	$5,784	$5,784
10	2022	$52,572	$65,715	$118,286	$49,680	$62,100	$111,780	$6,507	$6,507
11	2023	$52,858	$66,072	$118,929	$49,644	$62,055	$111,700	$7,230	$7,230
12	2024	$53,143	$66,429	$119,572	$49,609	$62,011	$111,620	$7,953	$7,953
13	2025	$53,429	$66,786	$120,215	$49,573	$61,967	$111,540	$8,676	$8,676
14	2026	$53,715	$67,143	$120,858	$49,538	$61,922	$111,460	$9,399	$9,399
15	2027	$54,001	$67,501	$121,501	$49,502	$61,878	$111,380	$10,122	$10,122
16	2028	$54,286	$67,858	$122,144	$49,467	$61,833	$111,300	$10,844	$10,844
17	2029	$54,572	$68,215	$122,787	$49,431	$61,789	$111,220	$11,567	$11,567
18	2030	$54,858	$68,572	$123,430	$49,395	$61,744	$111,140	$12,290	$12,290
19	2031	$55,144	$68,929	$124,073	$49,360	$61,700	$111,060	$13,013	$13,013
20	2032	$55,429	$69,287	$124,716	$49,324	$61,655	$110,980	$13,736	$13,736
21	2033	$55,715	$69,644	$125,359	$49,289	$61,611	$110,900	$14,459	$14,459
22	2034	$56,001	$70,001	$126,002	$49,253	$61,566	$110,820	$15,182	$15,182
23	2035	$55,429	$69,287	$124,716	$49,324	$61,655	$110,980	$13,736	$13,736
Present Value								**$159,355**	**$158,643**
Annualized								**$8,654**	**$8,615**

Costs for Constructed Wetlands

Year #	Year	Cost in Toledo	Cost in Duluth
1	2013	$0	$0
2	2014	$585,156	$1,434,576
3	2015	$0	$1
4	2016	$585,156	$1,434,576
5	2017	$0	$1
6	2018	$585,156	$1,434,576
7	2019	$0	$0
8	2020	$0	$0
9	2021	$0	$0
10	2022	$0	$0
…	…	$0	$0
20-Year Projections			
Summation		$1,755,468	$4,303,728
Present Value [a]		$1,700,543	$4,169,074
Annualized		$92,350	$226,405
50-Year Projections			
Summation		$1,755,468	$4,303,728
Present Value [a]		$1,700,543	$4,169,074
Annualized		$41,399	$101,495

Table Notes:

[a] Calculation of the present value uses a discount rate of 0.8 percent.

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APPENDIX E
TRANSFER OF DEVELOPMENT RIGHTS

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Transfer of Development Rights

Transfer of Development Rights (TDR) represents an innovative way to direct growth away from lands that should be preserved to locations well suited to higher density development. There are over 200 TDR programs in place across the country today. While most of these are geared to the preservation of open space or farmland, many communities are now considering the role of this tool in addressing impacts from climate change and flooding.

Certain areas that experience chronic flooding may be appropriate for preservation through TDR in order to play an important role for flood mitigation on a watershed scale. For example, in Toledo, OH, consideration of a TDR program whereby property rights are transferred from chronically flooded areas could potentially help shift development density away from the City's most flood-prone areas and into other areas more suitable for sustainable development. In Duluth, MN, a TDR program could potentially encourage development to occur in areas that are not prone to flooding and that would not displace important flood storage capacity (e.g., in closer proximity to the downtown Duluth area).

The approach to TDR begins with planning processes that identify specific preservation areas as "sending areas" and specific development districts as "receiving areas". Once these areas are identified, Zoning Ordinance amendments can be adopted which authorize landowners in the sending areas to sell their development rights to landowners in the receiving areas. The amount of money required to purchase these development rights is influenced by the ordinance provisions, but is generally negotiated between the landowners. This approach allows market forces to enter into the transaction and requires land owners to negotiate the final value of development rights. In other models, as discussed below, the local government can set a fixed value for density bonuses and have developers contribute to an open space fund in exchange for density bonuses.

In return for the purchase, landowners in the sending area place a restriction on their property, which is generally recorded as a deed restriction. This restriction can be determined through explicit zoning provisions or can be negotiated as part of the permitting process. Restrictions can limit the level of potential development, the type of development, or some combination of both.

Key Elements for a Successful TDR Program

TDR programs can have many moving parts and, for those just beginning to consider implementation, it can be difficult to determine what elements are necessary or important for success. The Journal of the American Planning Association published a short research article in the Winter 2009 issue entitled *What Makes Transfer of Development Rights Work?* (Pruetz and Standridge, 2009). This research piece examined the 20 most successful TDR programs in the nation at that time to see which elements were consistent across multiple programs. The results are summarized below. It should be noted that the first two elements are considered by Pruetz and other national experts as "essential" to the success of any program. The next three are considered "important", and the remaining are considered "helpful." The original article can provide more information about the study methodology and findings.

1. <u>Demand for Bonus Development</u>. The amount of density a developer can receive using TDR must be an attractive alternative to the density they can achieve by right. If the by-right density produces a product just as profitable as one with TDR, and it fits within the existing market demand, developers will have little incentive to pursue any transfers. However, if the allowable density bonus will increase developer profit and is a better fit for pent up market demand, the TDR program has a good chance of being viable. Although bonus

density is the most common motivation for developers to buy TDRs, many jurisdictions offer other incentives including additional lot coverage (Warwick Township, RI, Lancaster County, PA), floor area ratio (San Francisco, CA), floor area within an individual dwelling unit (Pitkin County, Colorado), and expedited issuance of building permits (Tahoe Regional Planning Agency, CA/NV).

2. <u>Customized Receiving Areas</u>. Receiving areas will be different with regard to many critical opportunities including, but not limited to:

- Desired level (density) and type (residential, commercial, etc.) of growth.
- Supporting infrastructure (water supply, roads, wastewater disposal, etc.).
- Market conditions.
- Political acceptability.

Research performed by Pruetz and Standridge demonstrated that there is no "hard rule" regarding how bonuses should be structured in a receiving area and that communities may have to work over several years to find the right balance between market reality and a community's desire for growth. Market and real estate analyses can assist communities with understanding how to best strike the balance and determine if TDR is a viable tool for better development. There are many possible receiving area options for jurisdictions to consider. Some communities succeed at locating receiving areas for TDRs from rural sending areas at infill sites within previously-developed urban areas including downtowns (South Lake Tahoe, CA). More commonly, receiving areas are found at the urban fringe where adopted plans may already call for continued growth since the new development would be close to existing jobs, schools and shopping as well as infrastructure (Montgomery County, MD). Some communities have overcome the potential for resident opposition to development by locating receiving areas in new towns or new villages that are not contiguous with existing development (Collier County, FL). Other communities recognize that development in low-density zones is inevitable and generate preservation by designating these zones as TDR receiving areas (Calvert County, MD).

3. <u>Strict Sending Area Development Regulations</u>. Landowners may be more apt to participate in a TDR program if development in the sending area is constrained by environmental factors such as wetlands or steep slope, or lack of infrastructure. However, Pruetz and Standridge found that most TDR studies emphasize the importance of sending area zoning that is strict or at least demonstrates that the community is serious about implementing its stated goals for preserving sending areas. In their research, "strict regulations" were those that prohibited densities greater than one unit per five acres.

4. Some communities have permissive zoning in their sending areas, and may find it necessary to down-zone to implement a TDR program as well as create consistency between zoning regulations and planning goals. This has its risks, and Pruetz and Standridge rightly caution communities to consider the implications of down-zoning, particularly as it relates to accusations that the new zoning takes private property for public use without just compensation, which is in violation of the Fifth Amendment of the U.S. Constitution. Whether or not a regulation will be found to be a taking depends on specific circumstances, but the most commonly cited rule comes from a 1992 U.S. Supreme Court decision: a regulation that eliminates all economic use of a property is a taking per se unless the use would have been prohibited by the state's underlying property and nuisance law. Jurisdictions are advised not to rely on the availability of TDR as their only legal defense

against a regulatory taking claim because the U.S. Supreme Court has not yet resolved the role of TDR compensation in these cases.

5. Few Alternatives to TDR. The most effective TDR programs offered developers few alternatives to utilizing TDR. Pruetz and Standridge noted that many communities may be inclined to offer a menu of incentives for development in desired growth areas. These could include density incentives for clustering, on-site open space dedication, streetscape improvements, design features, and other amenities. While these incentives may yield increased investment or public improvements, they will likely compete with TDR as an incentive vehicle and provide what developers perceive to be a simpler path to increased density.
6. Market Incentives, Transfer Ratios and Conversion Factors. TDR program transfer ratios determine the value of transferring one dwelling unit from a sending area to a receiving area. Many communities may try to use a one-to-one ratio, meaning that each unit from a sending area is equal to one bonus unit in the receiving area. However, it is likely that the profit yielded to the developer in the receiving area for one extra unit may not equal the profit reduction caused by preserving a large amount of land in the sending area. As a result, it is critical for any TDR program to identify a viable ratio between development rights in the sending area and bonuses in the receiving area.
7. In an effort to create market incentives, viable TDR programs offer an "enhanced transfer ratio," where more than one additional dwelling unit is allowed in the receiving area for each unit transfer from the sending area. Some communities also implement conversion factors, in which a TDR dwelling unit from a sending site can be converted to an increase in some other development potential at a receiving site, such as commercial floor area, building height or lot coverage.
8. Certainty of TDR Use. Communities will improve their chances of implementing successful TDR programs if they can demonstrate to developers that there is assurance that they will receive bonus density if they comply with all receiving area regulations including, of course, transferring the required number of TDRs. This can be achieved through zoning of the receiving area that eliminates or minimizes discretionary approvals, which can cause developer delays, unanticipated costs, and uncertainty if their project will be approved. Providing clarity in TDR regulations about what is required and what will be granted will also gain support of the development community in adopting a TDR program as demonstrated in Chesterfield Township, Burlington County, NJ.
9. Strong Public Preservation Support. TDR programs are successful if there is strong public support of overall preservation efforts. This is typically demonstrated by complementary preservation programs such as:
    - Local funding of a purchase of development rights (PDR) program.
    - Other conservation funding programs.
    - A TDR bank, in which a government entity purchases TDRs and holds them for resale to a developer.

10. This type of support can help communities overcome controversies that may arise over TDR components, such as locations of sending and/or receiving areas, which may be politically motivated. TDR programs last for decades, and elected officials will change over time. Ongoing public support is important to ensure that requests for exemptions to the TDR program do not erode its effectiveness.

11. Simplicity. TDR, when compared with other growth management tools, is inherently more complicated than most others. Crafting even a simple local program creates procedures and requires analyses that are new to most communities. To the greatest extent possible, keeping a TDR program's objectives and regulations clear and simple will help with its success. Simplicity leads to understanding and garners support from diverse groups, including elected officials, preservationists, developers, landowners, and the general public. A simpler program will also be easier to administer at the outset of implementation for everyone involved. The success of the TDR program in Montgomery County, MD can be partly credited to its simplicity.
12. Promotion and Facilitation. Keeping a TDR program visible and at the forefront of local land use discussions will help it succeed. Developers and landowners need to know it exists, how it works, and how it can help them. The public as well as local elected officials who make policy decisions need to understand its objectives to preserve land and other benefits. Promoting the program through a website or regular media coverage keeps the program in front of the public and maintains their continued support. Some jurisdictions, including the New Jersey Pinelands Commission, continually maintain ongoing public support for preservation by organizing educational and recreational programs in and about their sending areas.
13. TDR Bank. The final successful factor identified by Pruetz and Standbridge is the establishment of a TDR bank. A TDR bank is a mechanism used by a government entity to buy, hold and sell TDRs. While not critical to a successful program, TDR banks are helpful and can enhance a program by allowing the program to:
    - Acquire TDRs from sending area landowners who cannot find private buyers.
    - Establish and stabilize TDR prices.
    - Facilitate transactions.
    - Market the TDR program.
    - Create an ongoing preservation revolving fund by selling TDRs and using the proceeds to buy more TDRs.

The Mechanics of Implementing Local TDR Programs

The key elements ("top 10 elements") of a successful TDR program provided above discuss the programmatic, market, and political conditions that are either necessary or helpful to success. Some of those elements are discussed here again in more detail, but also specifically in the context of local implementation. Once a community (or more than one community) decides to actually implement TDR—to put it "on the books"—the mechanics of the program must be addressed at a more detailed level. The points listed below provide the framework for a technical work plan at the local level.

1. Strong Comprehensive Plan Language

   Every community looking to implement TDR should address this in their Comprehensive Plan. Beginning with a policy-based discussion, as opposed to tackling the ordinance first, will help to develop consensus on key questions related to TDR such as:

   - What parts of the community will serve as sending and receiving areas?

- Are certain types of sending areas more important to the community (e.g., forest lands, aquifer protection districts, agricultural lands, etc.)?
- How much density is a community willing to accept in the receiving area?
- Should strict design standards be developed for the receiving area?
- What types of restrictions should be placed on sending area lands once the development rights are purchased?

2. Clear Sending and Receiving Areas

TDR programs across the country vary as to how clearly sending and receiving areas are defined. In some cases, such as Chesterfield Township, New Jersey, jurisdictions are able to make the transfer process administrative by not only designating specific sending and receiving sites but also adopting non-discretionary receiving site zoning that incorporates all the development regulations including the TDR requirements. Developers are logically inclined to use programs of this nature because they do not have to endure the time, cost and uncertainty of a rezoning or other discretionary approval processes. However, in many other jurisdictions, including San Luis Obispo County, CA, sending and receiving sites can be proposed by applicants and approved according to how well the proposed sites meet predetermined criteria. San Luis Obispo County preferred this approach at least in part because of the size and diversity of the county. Each jurisdiction has to choose a path that fits local circumstances. These strategic decisions are less complicated within a jurisdiction than they are when two or more jurisdictions must coordinate and sign interlocal agreements. With local programs, because a single municipal entity can plan the full scope of TDR transactions, there is an opportunity to be very clear from the outset where development rights can come from, and where they can be used to yield density bonuses.

3. Design Standards for Receiving Areas

One of the primary functions of TDR is to increase density in a designated receiving area. Presumably, this density will take place in the form of larger buildings that can often incorporate mixed use, multi-family housing in communities that have not previously allowed high density development. Many communities looking to grant these higher levels of density may want some assurance that the development will incorporate a high quality of design. Many TDR programs apply design guidelines or design standards to their receiving areas as part of the program's regulatory component to provide these assurances. This approach is not only truly protective of community character, but can also be very effective in overcoming public fear of higher levels of development density.

When considering the use of design guidelines or standards (especially if they are discretionary), it is important to remember that TDR programs create a development process that is inherently more complex than a standard by-right approach. The imposition of design standards can add another layer of complexity to the development process and, if too onerous or complicated, can create a significant disincentive for developers to pursue TDR. Communities must carefully consider how strict and/or detailed design standards can be in order to balance the need for high quality design with the need to remain attractive to the development community. However, specific development regulations and design requirements can be imposed using by-right zoning. While this non-discretionary approach may not fully dispel all concerns, it can strike a balance between motivating developers to use TDR and create reasonable assurance that the receiving area developments will be a credit to the TDR program.

4. Market-Based TDR Ratios

In order for TDR to succeed, developers must want the bonus development that they can only get via TDR. If market demands are strong, developers are more likely to consider a more complex path to permit approval. Further, TDR is not a "break even" proposition for developers. The act of purchasing development rights will need to increase a developer's profits beyond what would be realized without the use of TDR. To build this into the regulatory structure, TDR programs must identify a viable "TDR ratio." A TDR ratio identifies the number of receiving area bonuses a developer receives for every development right (s)he purchases. For example, a TDR program might assign a single development right for every single family home that could be built in the sending area. For every one of these development rights that is extinguished through a developer's purchase, the developer will then be able to build four additional multi-family units. In this simple example, the TDR ratio is "one to four". Other programs across the country develop more innovative ratios to provide bonuses for building height, commercial floor area, floor-to-area ratio (FAR), and other similar items.

In order for a TDR program to be successful, the TDR ratio must be attractive enough to a developer from the perspective of his or her bottom line. Communities looking to TDR should consider specific market and/or real estate analyses that will identify a viable TDR ratio. The analysis that is most commonly used to identify this ratio is called a "residual land value" analysis. This analysis actually develops a basic development pro forma to identify how much developers should reasonably be able and willing to pay for a TDR. These analyses can also be used to identify the appropriate fee-in-lieu[61] value for communities that wish to pursue that option (discussed below).

5. Fee-in-Lieu Mechanism

Fee-in-lieu is a regulatory mechanism that has been used for many decades for different purposes. The earliest applications were often used to offset required amounts of open space as part of development. In these instances, developers could either include required open space as part of their proposal, or they could submit a fee to the city or town that would then be used to set aside open space elsewhere. For example, where on-site options for flood storage are limited in Duluth, MN, the City may consider "fee-in-lieu-of" on-site stormwater improvements, where fees are put into a fund for implementing some watershed-based solutions, such as open space preservation and protection and enhancement of wetlands. This type of fee would be set through a pre-determined formula and money would be held in a fund dedicated to the preservation of open space.

More recently, some TDR programs have offered a fee-in-lieu of transferring development rights as an optional approach. So instead of actually extinguishing development rights in the sending area as part of the permitting process, developers can provide a payment that is held in an account dedicated to the preservation of open space. This account can be administered by the city or town, or by a newly appointed entity that is dedicated to purchasing development rights. As discussed in the section on TDR ratios above, the value of development rights—the basis for the fee—is best determined through a residual land value analysis. This value should be adjusted as property values change over time to ensure a reasonable fee.

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[61] Also referred to as "Density Transfer Charge" (DTC). Some practitioners prefer the term DTC rather than "fee" because DTC is a substitute for TDRs, and TDRs are only required when developers voluntarily choose to exceed baseline and are only required for bonus development, meaning bonus dwelling units or floor area in excess of baseline. Therefore, it does not fit the traditional, case law framework established for "fee-in-lieu".

6. TDR Bank

Although not critical to the success of a local program, the establishment of a TDR bank has proved to be helpful in some instances.[62] The primary function of a TDR bank is to hold development rights that have been extinguished, but have not yet been sold to a developer. Banks can play an active role in facilitating TDR transactions, can actively purchase development rights, and can add administrative capacity. In many cases, the technical assistance provided by banks is their most powerful role. Providing funds/expertise for real estate analysis, organizing and tracking the sale of development rights, and serving as a user-friendly clearinghouse for development rights are examples of how banks can simplify this inherently complex process.

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[62] In the 20 top national programs examined by Pruetz and Standbridge in *What Makes Transfer of Development Rights Work?,* four used a TDR bank.

APPENDIX F
LIST OF PARTICIPANTS

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APPENDIX G
HAZUS METHODOLOGY AND DATA SOURCES

Introduction

This appendix provides a detailed description of the methodology, software limitations, data inputs and outputs, and assumptions used to estimate building flood damages in the project study areas.

FEMA's Hazards U.S. – Multi Hazard (Hazus-MH or Hazus) Flood Module was used to estimate the flood damages. Specifically, Hazus-MH 2.0, Service Pack 2 (Release 11.0.2) on ESRI's ArcGIS 10.0, Service Pack 2 (Build 3200). Hazus is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes.

As described in the report, Hazus can operate at three levels depending on the needs and expertise of the user. A Level 2 analysis integrates detailed user-supplied data such as building footprint locations or parcel centroids as a proxy for building locations or flood depth data from engineering based software such as HEC-RAS. A Level 2 analysis was completed for this project by importing parcel centroids as User-Defined Facilities (UDF) and additionally by importing flood depth grids generated by the HEC-RAS models. The UDF analysis provides estimated flood damage for each parcel centroid as the main output.

The limitations associated with the Hazus Flood Module and overall study area analyses are described in the next section. The next section describes the detailed methodology used for both communities, which is followed by the last section that provides assumptions used for formatting UDF data for Toledo, Ohio then Duluth, Minnesota.

Limitations – Hazus Flood Module

The building damage results estimated by Hazus can be improved by using local data (e.g. parcels with assessed value) versus using the national datasets (e.g. census blocks with estimated building values) included with Hazus. However, even with improved local data the Hazus building damage estimates should not be represented as absolute values for flood damages in any study area. Hazus estimated damages should be used as guidance for community planning alternatives and identification of potential risk. In other words, by comparing where damages occur as a result of different planning or flood risk scenarios the community can see how different proposed options increase or decrease potential cost to property owners and the overall community.

Comparison of damages between scenarios (e.g. future climate or future land use scenarios) is possible since the underlying building dataset and values are held constant allowing stakeholders to look at relative changes. For example, does the addition of green infrastructure or low impact development options into a community decrease flood inundation, which subsequently reduce flood damages when compared to current land use conditions? This type of question and comparison between scenarios is appropriate for the modeling efforts being conducted with this study.

As with any modeling software, further limitations were encountered due to unavailable or incomplete datasets and attributes for both communities. For example to develop the User-Defined Facility (UDF) datasets, accurate building locations that represent individual houses do not exist or are incomplete. Further, incomplete attributes (e.g. empty descriptions of building foundation type) require additional assumptions to be made, which increases the uncertainty or variability in the modeled results. The detailed methodology provided below for both communities describes the assumptions made during the data formatting and cleanup process.

As described in the main report building footprints are the ideal source for capturing the correct number of buildings and the most accurate location; however complete building footprints were not available from either community. Therefore the center point of the parcel (parcel centroid) was used to approximate where a building was located on the parcel, thus serving as a building proxy. When using the parcel centroid, it is assumed that there is only one building per parcel; it is recognized that some parcels will have multiple buildings and others parcels will be vacant and additionally that the building will not always be located at the parcel center. Overall, the parcel centroid produces a reasonable building proxy for both, location within the parcel, and number of buildings on the parcel since residential buildings are the predominant building type for both communities (typical residential parcels only have one house per parcel and it is generally located in the center). See below how some of the assumptions related to building attributes were dealt with during data formatting for each of the communities.

Hazus damage estimates for this study are also limited to buildings (e.g. houses or retail stores) and do not include structures like bridges, culverts that in the case of Duluth, MN were damaged as a result of runoff velocity and erosion. For the Duluth, MN flood damage estimates the major limitation with Hazus stems from flood damages that are the result of flow velocity and erosion hazards, meaning there is less damage due to flood inundation. Hazus does not estimate damages as a result of flow velocity or erosion.

Finally, unless included as part of the hydrology and hydraulic modeling, Hazus does not account for antecedent conditions or prior flood conditions such as saturated ground due to previous rainfall.

Process Methodology

This section describes the processing steps required to run Hazus starting with data collection through exporting the final results.

1. Identify and acquire flood inundation area datasets:
    a. Flood hazard areas – for this analysis we are using flood depth grid (raster format) datasets produced by the US Army Corps of Engineers that are output results from Hydrologic and Hydraulic (H&H) engineering software such as HEC-HMS and HEC-RAS

2. Identify and acquire building datasets and attributes
    a. Building locations for both Toledo and Duluth are based on using the parcel centroid as a proxy for the building location within the parcel boundary
    b. Building values and attributes – each community supplied a parcel database that had links to the real estate assessor data collected. These databases are used to populate the required Hazus attributes (see below)

3. Data formatting – buildings datasets
    a. Create parcel centroid representing the structure location (proxy location) – this process is carried out using GIS software to generate the center point
    b. Populate required Hazus attributes using community assessor data – this is a manual, multi-step process that requires GIS and database expertise. The detailed steps are beyond the scope of this appendix
    c. Populate empty or incomplete attributes based on assumptions (see below)

4. Data formatting – flood inundation datasets

   a. No formatting was required to prepare the HEC-RAS flood depth grids for import and use within Hazus

5. Import HEC-RAS flood depth grids (raster datasets) – a.k.a. "user-defined depth grids"
   a. Hazus reformats the depth grids for internal processing

6. Select user-defined depth grids
   a. Hazus requires the user to select specific depth grids that will be used for determining flood loss estimations

7. Delineate floodplain
   a. This step converts the imported depth grid for internal processing

8. Import formatted building data into Hazus User-defined Facilities (UDF) table

9. Run UDF Analysis on each for each scenarios (e.g. current climate, current land use)

10. Export UDF point feature class for each scenario and flood recurrence interval

Hazus Required Attributes

Listed below are the required attributes with highest importance for determining flood loss estimates utilizing Hazus' User-Defined Facilities (UDFs). Each of these attributes must be populated with a valid value in order to run the analysis. The assumptions made in order to populate these values for both communities are provided in the next section.

- Occupancy Type – residential, commercial, retail
- Structure Cost – assessed, market, replacement
- First Floor Elevation – height of first floor above the ground
- Square Footage of the building footprint – area of first floor
- Foundation Type – basement, slab-on-grade, crawlspace
- Stories – 1, 2 or more
- Year Built

Building Dataset and Attribute Assumptions

Toledo, OH – Hazus Assumptions:

The Lucas County Auditor's Real Estate Information System (AREIS) was used to populate the required Hazus attributes needed for analysis. The following major assumptions were made in order to ensure that all attributes were populated:

- Occupancy Type
  - If the Occupancy Type attribute was "Null" or "0" meaning that AREIS attribute was blank, then the attribute value was set to equal Residential (Hazus value = "RES1").
- Structure Cost
  - If the Structure Cost attribute was "Null" or "0-NONE" meaning the AREIS attribute was blank, then the attribute value was set to the average cost of a structure in the watershed.
  - Cost was found in the table COLLECTION, in the field BLDG, which is assumed to be the assessed value of the structure on the property. Hazus requires the cost be in

thousands, so cost is equal to the value in BLDG multiplied by 0.001 (which makes an actual cost value of 100,000 equal to 100 in Hazus). If the parcel had "0" for cost or did not exist in the COLLECTION table, the value was set to the average of all structures that had a cost, which was 31.33 (or $31,330).

- First Flood Elevation and Foundation Type
  - No records or attributes exist within the AREIS database that describes the first floor height (elevation) for buildings. This information could come from Elevation Certificates maintained by the City of Toledo's Floodplain Manager, but Elevation Certificates are usually not available for every structure within the community.
  - In this case, the assumption has been made that the foundation type can indicate the first floor height or elevation as described in the Hazus User Manual based on nationally reviewed values.
  - If the attribute was "Null", "0-NONE", "1-FULLSLAB" then the value was set to equal "Slab on Grade" with the First Floor Height set to "1-foot".
  - If attribute was "2-FULLCRWL", "3-SLABCRW" then the Foundation Type value was set to equal "Crawlspace" with the First Floor Height set to "3-foot".
  - If attribute was "4-BSMTSLAB", "5-BSMTCRSL", "6-BSMTCRSL", "7-FULLBSMT" then the Foundation Type value was set to equal "Basement" with the First Floor Height set to "4-foot".
- Square Footage
  - If the Square Footage attribute was "Null" or "0-NONE" meaning the AREIS attribute was blank, then the Square Footage value was set to equal the average square footage for all structures in the entire watershed, which was 1,040 square feet
  - Square Footage for residential structures was found in the RESIDENTIAL table in the field "Sfla1" (assumed to be Square Footage Living Area, 1st floor) and was set was set to that value.
- Number of Stories
  - The number of stories is important in determining the square footage for just the first floor of a structure because often the assessor database provides the overall square footage of a structure. Since Hazus uses just the first floor square footage in determining damage estimates, the overall square footage is divided by the number of stories.
  - The number of stories was available for most structures. If the "Number of Stories" attribute was "Null", "0-NONE" meaning the AREIS attribute was blank, then the Number of Stories attribute was assumed to be 1 story.
- Year Built
  - If the Year Built attribute was "Null" or "0-NONE" meaning the AREIS attribute was blank, then the Year Built value was set to equal the average year built for all structures in the entire watershed, which was 1941.

Duluth, MN – Hazus Assumptions:

The City of Duluth's GIS databases DLHGISData.gdb (containing, among other things, the GIS data for Parcels and Zoning) and DLHParcelInfo.gdb (containing tables with Building, Parcel and Value data) were used to populate the required Hazus attributes needed for analysis. The following assumptions were made in order to ensure that all attributes were populated:

- Occupancy Type
  - The Duluth parcel data did not contain occupancy types but did have a spatial zoning layer that was used via a spatial join to append an occupancy type to the parcel centroids.

  - Residential, Commercial and Industrial zoning were assigned to the corresponding occupancy type, RES1, COM1, and IND1, respectively. “Mixed Use” was assigned to RES1 and “Mixed Use Commercial” was assigned to COM1.
- Structure Cost
  - Cost was assigned from the “Building Value” field in the Parcel dataset. Where values were listed as “0” the average of building values was used, which was 190.75 in thousands as Hazus requires, or $190,750.
- First Flood Elevation and Foundation Type
  - There was also no explicit field for first floor elevations or foundation types, but the same “StyleCodeDescription” table contained a value “SLAB” so the foundation type was assigned to “7” (which corresponds to a slab on grade foundation type in Hazus) and a first floor height of “1.”
  - All other foundation types were set to “4” for basement and the first floor height set to a height of “4.” Hazus manual gives these default first floor heights for the corresponding foundation types. On the ground knowledge could be used to find better approximations to these values.
- Square Footage
  - The “vwBuilding” table contains a field called “MainFloorSquareFeet” which was used for the area. Where the data provided a “0” for this value, an average of all the “MainFloorSquareFeet” was used, 1.646 (in thousands for Hazus) or 1,646 square feet.
- Number of Stories
  - There was no explicit field for number of stories in the data, but the “vwBuilding” table contained a field named “StyleCodeDescription” which was used to approximate the number of stories for Hazus.
  - Most of the values were assigned a number of stories value of “1” unless the code stated the actual numbers of stories, such as “2 STORY” or “MULTILEVEL” which were assigned a value of “2,” or “HI RISE” which was assigned a value of “3.”
- Year Built
  - The “vwBuilding” table contains a field called YearBuilt which was used for the year. Where the data provided a “0” for this value, an average of all the YearBuilt was used, calculated to be 1942.

The table below provides a detailed description of the data inputs and outputs used by Hazus to estimate building flood damages in the project study areas.

The four scenarios described below are as follows:

1. Scenario 1 = Current land use and current precipitation (2013)
2. Scenario 2 = Future land use and future precipitation (2035)
3. Scenario 3 = Current land use and current precipitation (2013) with Green Infrastructure
5. Scenario 4 = Future land use and future precipitation (2035) with Green Infrastructure

Toledo, OH

Data Inputs	File Name	File Type	Description
Parcels	lucas.shp	ESRI GIS Shapefile	Parcel boundaries
Parcel Assessment Values	Viewer.mdb Individual Tables: • UNIVERSAL_CODE_LOOKUP (Occupancy Type) • COLLECTION (Structure Cost) • RESIDENTIAL (Square Footage) • BsmtType_LV (Foundation) • STORY_LV (Number of Stories)	Access database	Lucas County Auditor's Real Estate Information System (AREIS) – assessor database for parcel data including assessed values, foundation type, number of stories, occupancy type (e.g. residential, commercial, retail)
User-defined Facilities (UDF)	HAZUS_UDF_Toledo_GeoDB.mdb	ESRI GIS Geodatabase	Geodatabase of centroids derived from Parcels and AREIS datasets.
Flood Depth Grids: 1. Scenario 1: 2. Scenario 2: 3. Scenario 3: 4. Scenario 4:	File name varies, but available for following recurrence intervals for each scenario. 1. 2 yr, 5yr, 10yr, 25yr, 50yr, 100yr 2. 2 yr, 5yr, 10yr, 25yr, 50yr, 100yr 3. 2 yr, 5yr, 10yr, 25yr, 50yr, 100yr 4. 2 yr, 5yr, 10yr, 25yr, 50yr, 100yr	GIS Raster	Depth Grids derived from HEC-RAS for running Hazus Analysis.

Data Outputs	File Name	File Type	Description
Hazus User-Defined Facility (UDF) Results: 1. Scenario 1: 2. Scenario 2: 3. Scenario 3: 4. Scenario 4:	File name varies based on recurrence interval: 1. UDF_toledo_[x]year.shp (2, 5, 10, 25, 50, 100 year) 2. UDF_toledo_[x]year_2035.shp (2, 5, 10, 25, 50, 100 year) 3. Toledo_Storage_CurrentPrecip_[x]yr.shp (2, 5, 10, 25, 50, 100 year) 4. Toledo_Storage_2035Precip_[x]yr.shp (2, 5, 10, 25, 50, 100 year)	ESRI GIS Shapefile	Output of running Hazus on UDF centroids against provided depth grids for each of the years for each scenario.
Hazus UDF Results	Toledo_Hazus_Damage_Results_20131115.xlsx	Excel File	Summarized outputs from UDF GIS data for all scenarios

Duluth, MN

Data Inputs	File Name	File Type	Description
Parcels and Zoning	DLHGISData.gdb	ESRI Geodatabase	Geodatabase containing parcel and zoning (used for Occupancy Type) boundary feature classes
Parcel Assessment Values	DLHParcelInfo.gdb	ESRI Geodatabase	Geodatabase containing tables with parcel data including assessed values, foundation type, number of

Data Inputs	File Name	File Type	Description
	Individual Tables: - vwValue (Structure Cost) - vwBuilding (Number of Stories, Foundation, Square Footage, Year Built) (Occupancy Type)		stories, occupancy type (e.g. residential, commercial, retail)
User-defined Facilities (UDF)	HAZUS_UDF_Duluth.mdb	ESRI Geodatabase	Geodatabase of centroids derived from Parcels & Zoning and Parcel Assessed Value databases above
Flood Depth Grids: 1. Scenario 1: 2. Scenario 2: 3. Scenario 3: 4. Scenario 4:	File name varies, but available for following recurrence intervals for each scenario. 1. 2 yr, 5yr, 10yr, 25yr, 50yr, 100yr, 500yr 2. 2 yr, 5yr, 10yr, 25yr, 50yr, 100yr, 500yr 3. 2 yr, 5yr, 10yr, 25yr, 50yr, 100yr, 500yr 4. 2 yr, 5yr, 10yr, 25yr, 50yr, 100yr, 500yr		Depth Grids derived from HEC-RAS for running Hazus Analysis.

Data Outputs	File Name	File Type	Description
Hazus User-Defined Facility (UDF) Results: 1. Scenario 1: 2. Scenario 2: 3. Scenario 3: 4. Scenario 4:	File name varies based on recurrence interval: 1. UDF_duluth_[x]year.shp (2, 5, 10, 25, 50, 100, 500 year) 2. UDF_duluth_[x]year_2035.shp (2, 5, 10, 25, 50, 100, 500 year) 3. Duluth_Storage_CurrentPrecip_[x]yr.shp (2, 5, 10, 25, 50, 100, 500 year) 4. Duluth_Storage_2035Precip_[x]yr.shp (2, 5, 10, 25, 50, 100, 500 year)	ESRI GIS Shapefile	Output of running Hazus on UDF centroids against provided depth grids for each of the years for each scenario.
Hazus UDF Results	Duluth_Hazus_Damage_Results_20131115.xlsx	Excel File	Summarized outputs from UDF GIS data for all scenarios

APPENDIX H

HYDROLOGY AND HYDRAULICS METHODOLOGY AND DATA SOURCES

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Overview

This study utilized USGS regression equations and HEC-RAS for H&H modeling. Below is a summary of data used in the H&H modeling for this study. There are many ways in which to perform H&H analyses. The H&H method and data used in this study is one option for analysis. The components and data inputs listed below are not the only means to reach the end results of obtaining peak discharges and flood depth grids.

General sources of data

- State/Local/Other GIS
- Land use data (present and future)
- Aerial imagery (Bing, GoogleEarth)

Land Cover Datasets

- National Land Cover Database 2001, 2006, and 2011 (http://www.mrlc.gov/nlcd01_data.php,http://www.mrlc.gov/nlcd06_data.php and http://www.mlrc.gov/nlcd11_data.php)
- Coastal Change Analysis Program (C-CAP) Land Cover and Land Change (http://www.csc.noaa.gov/ccapatlas/)

Hydrological Datasets

- USGS National Hydrograph Dataset (NHD) (http://nhd.usgs.gov/data.html)
- NHDPlus Version 2 (http://www.horizon-systems.com/NHDPlus/NHDPlusV2_home.php)
- USGS StreamStats (http://water.usgs.gov/osw/streamstats/)

Climate Data

- Rainfall data (TP-40, Atlas 14, CREAT)

Elevation Data

- Shuttle Radar Topographic Mission (SRTM) (https://lta.cr.usgs.gov/SRTM2)
- USGS National Elevation Dataset (NED) (http://ned.usgs.gov/)
- NSF OpenTopography (http://www.opentopography.org/)
- United States Interagency Elevation Inventory (http://www.csc.noaa.gov/inventory/)
- State/Local/Other LiDAR

USGS Regression Equations

Note that for this study the USGS regression equations from the Water-Resources Investigations Report 94-4002 titled “Nationwide Summary of U.S. Geological Survey Regional Regression Equations for Estimating Magnitude and Frequency of Floods for Ungaged Sites, 1993” were used (http://pubs.usgs.gov/wri/1994/4002/report.pdf).

USGS regression equations for Minnesota could also be obtained from Water-Resources Investigations Report 97-4249 titled “Techniques for Estimating Peak Flow on Small Streams in Minnesota” (http://mn.water.usgs.gov/publications/pubs/97-4249.pdf). USGS regression equations for Ohio could also be obtained from Water-Resources Investigations Report 03-4164 titled “Techniques for Estimating Flood-Peak Discharges of Rural, Unregulated Streams in Ohio” (http://oh.water.usgs.gov/reports/wrir/wrir03-4164.pdf).

Toledo USGS Regression Equations (http://pubs.usgs.gov/wri/1994/4002/report.pdf)

- **Rural Regional Equations:**

$$Q2 = (RC)A^{0.782}\, S^{0.172}\, (St+1)^{-0.297}$$
$$Q5 = (RC)A^{0.769}\, S^{0.221}\, (St+1)^{-0.322}$$
$$Q10 = (RC)A^{0.764}\, S^{0.244}\, (St+1)^{-0.335}$$
$$Q25 = (RC)A^{0.760}\, S^{0.264}\, (St+1)^{-0.347}$$
$$Q50 = (RC)A^{0.757}\, S^{0.276}\, (St+1)^{-0.355}$$
$$Q100 = (RC)A^{0.756}\, S^{0.2859}\, (St+1)^{-0.363}$$

- **Urban Regression Equations:**

$$UQ2 = 2.35\, A^{.41}\, SL^{.17}\, (RI2+3)^{2.04}\, (ST+8)^{-.65}\, (13\text{-}BDF)^{-.32}\, IA^{.15}\, RQ2^{.47}$$

standard error of estimate is 38 percent

$$UQ5 = 2.70\, A^{.35}\, SL^{.16}\, (RI2+3)^{1.86}\, (ST+8)^{-.59}\, (13\text{-}BDF)^{-.31}\, IA^{.11}\, RQ5^{.54}$$

standard error of estimate is 37 percent

$$UQ10 = 2.99\, A^{.32}\, SL^{.15}\, (RI2+3)^{1.75}\, (ST+8)^{-.57}\, (13\text{-}BDF)^{-.30}\, IA^{.09}\, RQ10^{.58}$$

standard error of estimate is 38 percent

$$UQ25 = 2.78\, A^{.31}\, SL^{.15}\, (RI2+3)^{1.76}\, (ST+8)^{-.55}\, (13\text{-}BDF)^{-.29}\, IA^{.07}\, RQ25^{.60}$$

standard error of estimate is 40 percent

$$UQ50 = 2.67\, A^{.29}\, SL^{.15}\, (RI2+3)^{1.74}\, (ST+8)^{-.53}\, (13\text{-}BDF)^{-.28}\, IA^{.06}\, RQ50^{.62}$$

standard error of estimate is 42 percent

$$UQ100 = 2.50\, A^{.29}\, SL^{.15}\, (RI2+3)^{1.76}\, (ST+8)^{-.52}\, (13\text{-}BDF)^{-.28}\, IA^{.06}\, RQ100^{.63}$$

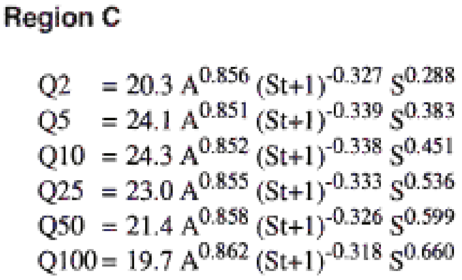
standard error of estimate is 44 percent

$$UQ500 = 2.27\, A^{.29}\, SL^{.16}\, (RI2+3)^{1.86}\, (ST+8)^{-.54}\, (13\text{-}BDF)^{-.27}\, IA^{.05}\, RQ500^{.63}$$

standard error of estimate is 49 percent

Duluth USGS Regression Equations (http://pubs.usgs.gov/wri/1994/4002/report.pdf)

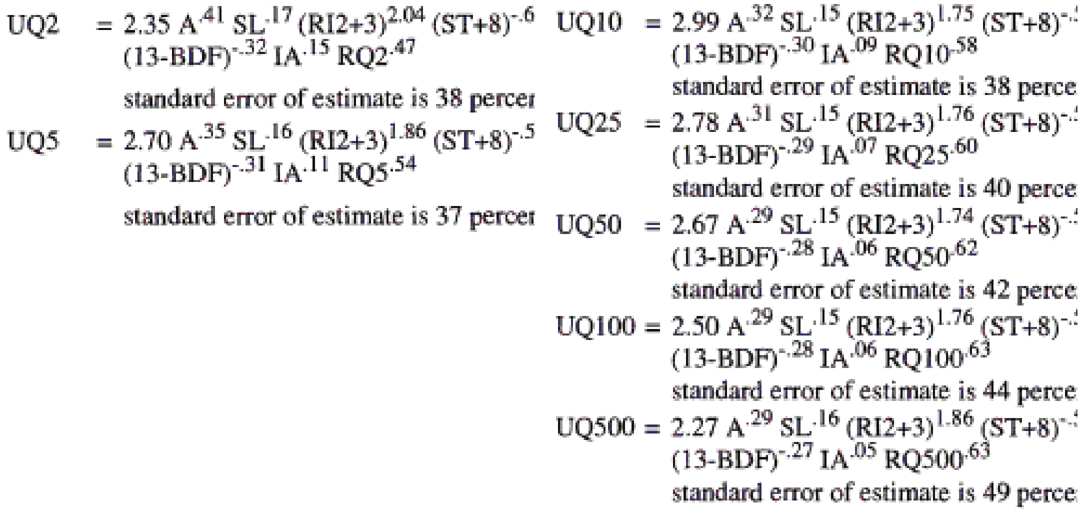
- **Rural Regional Equations:**



Region C

$Q2 = 20.3\ A^{0.856}\ (St+1)^{-0.327}\ S^{0.288}$
$Q5 = 24.1\ A^{0.851}\ (St+1)^{-0.339}\ S^{0.383}$
$Q10 = 24.3\ A^{0.852}\ (St+1)^{-0.338}\ S^{0.451}$
$Q25 = 23.0\ A^{0.855}\ (St+1)^{-0.333}\ S^{0.536}$
$Q50 = 21.4\ A^{0.858}\ (St+1)^{-0.326}\ S^{0.599}$
$Q100 = 19.7\ A^{0.862}\ (St+1)^{-0.318}\ S^{0.660}$

- **Urban Regression Equations:**



$UQ2 = 2.35\ A^{.41}\ SL^{.17}\ (RI2+3)^{2.04}\ (ST+8)^{-.6}$
$(13\text{-}BDF)^{-.32}\ IA^{.15}\ RQ2^{.47}$
standard error of estimate is 38 percen

$UQ5 = 2.70\ A^{.35}\ SL^{.16}\ (RI2+3)^{1.86}\ (ST+8)^{-.5}$
$(13\text{-}BDF)^{-.31}\ IA^{.11}\ RQ5^{.54}$
standard error of estimate is 37 percen

$UQ10 = 2.99\ A^{.32}\ SL^{.15}\ (RI2+3)^{1.75}\ (ST+8)^{-.}$
$(13\text{-}BDF)^{-.30}\ IA^{.09}\ RQ10^{.58}$
standard error of estimate is 38 perce

$UQ25 = 2.78\ A^{.31}\ SL^{.15}\ (RI2+3)^{1.76}\ (ST+8)^{-.}$
$(13\text{-}BDF)^{-.29}\ IA^{.07}\ RQ25^{.60}$
standard error of estimate is 40 perce

$UQ50 = 2.67\ A^{.29}\ SL^{.15}\ (RI2+3)^{1.74}\ (ST+8)^{-.}$
$(13\text{-}BDF)^{-.28}\ IA^{.06}\ RQ50^{.62}$
standard error of estimate is 42 perce

$UQ100 = 2.50\ A^{.29}\ SL^{.15}\ (RI2+3)^{1.76}\ (ST+8)^{-.}$
$(13\text{-}BDF)^{-.28}\ IA^{.06}\ RQ100^{.63}$
standard error of estimate is 44 perce

$UQ500 = 2.27\ A^{.29}\ SL^{.16}\ (RI2+3)^{1.86}\ (ST+8)^{-.}$
$(13\text{-}BDF)^{-.27}\ IA^{.05}\ RQ500^{.63}$
standard error of estimate is 49 perce

H&H Modeling Data

H&H Component	Data Inputs	Units	Description	Output
Regional USGS Regression	Drainage Area	Square miles	Area of the watershed determined from maps/GIS/topo	Peak Discharge (cfs) for the 2-, 5-, 10-, 25-, 50-, 100-, 500-year recurrence intervals
	Basin storage	Percent	Percent of drainage area basin occupied by lakes, reservoirs, swamps, and wetlands	
	Main channel slope	Feet/mile	Slope of the channel within the watershed	
Urban USGS Regression	Watershed drainage area	Square miles	Area of the watershed determined from maps/GIS/topo	
	Main channel slope	Feet/mile	Slope of the channel within the watershed	
	Basin storage	Percent	Percent of drainage area basin occupied by lakes, reservoirs, swamps, and wetlands	
	Basin development factor	Unitless	Index of the prevalence of the urban drainage improvements	
	Percent impervious area	Percent	Percent of area in the watershed that covered by impervious surfaces	
	TP-40 2-year, 2-hour rainfall	Inches	Calculated rainfall amount received for a 2-year, 2-hour storm determined from U.S. Weather Bureau Technical Paper 40 or from NOAA Atlas 2	
	Rural peak discharge for the region	cfs	Peak discharges computed from the rural USGS regression equations for the appropriate State	
HEC-GeoRAS Pre-processing	Stream centerlines	N/A	The center line of a stream to represent the deepest part of the channel that is used to generate cross sections of the stream	• Stream cross sections • Stream centerlines
	Hydrology Digital Elevation Model (DEM)	N/A	Raster/grid that allows for continuous hydrological surface flow	

H&H Component	Data Inputs	Units	Description	Output
HEC-RAS	USGS Regression Equations	cfs	Peak discharges	• Peak Velocities (ft/s) for the 2-, 5-, 10-, 25-, 50-, 100-, 500-year recurrence intervals • Peak Discharges (cfs) for the 2-, 5-, 10-, 25-, 50-, 100-, 500-year recurrence intervals
	Previous models, local knowledge	N/A	Any additional input that can refine the input data	
HEC-GeoRAS Post-processing	Hydrology DEM	N/A	Raster/grid that allows for continuous hydrological surface flow	• Flood depth grids • Inundation polygons
	HEC-RAS Geometry	N/A	Stream channel geometry with associated discharge, velocity, and depth information	